THE CHEMISTRY
OF
CROP PRODUCTION

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BY

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PREFACE.

In this little book I have attempted to set out in the form of a connected story the scientific principles of crop production. In doing so I am fully aware that I have omitted many details of great practical importance which every student should know. I have done this advisedly, in the hope that the story of the factors of productivity will awaken in the students who read it an interest in the subject which will stimulate them to fill in these details, by consulting larger and more ambitious works on Agricultural Chemistry. The book should be read side by side with a course of practical laboratory work such as Newman and Neville's *Practical Agricultural Chemistry* published by the Cambridge University Press.

I have assumed that students who use the book possess an elementary knowledge of the principles of chemistry, and that they are familiar with simple chemical and physical manipulation. The illustrations and the tables of soil analyses in Chapter II. were prepared by my colleague Mr. L. F. Newman, M.A., F.I.C., Fellow of St. Catharine's College, with the assistance of Mrs. Nodder, to both of whom I record my best thanks. I wish to thank Mr. Newman also for reading the proofs and Mr. C. W. Williamson for preparing photographs of the illustrations and for checking the results of the experiments.

T. B. WOOD.

Cambridge,
September 4th, 1920

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CHAPTER I

THE FACTORS OF PRODUCTIVITY OF THE SOIL.

Factors of Productivity.

Thirty years ago the consensus of opinion as to the relation of chemistry to agriculture was that the chemist could analyse the farmer's soils and manures and tell him exactly what manures he should use in order to secure a profitable crop. Since then our ideas on the subject of crop production have been widened by the labours of investigators in the allied sciences of Botany, Bacteriology, Geology, and Physics in their relation to agriculture. We know, for instance, that many factors are concerned in crop production besides the provision of suitable manures for the soil and crop, and the first and perhaps the most important thing the student of agricultural chemistry must learn is the part played by these various factors.

Water.

If we put a small quantity of freshly cut grass into a test-tube and warm it moderately over a flame, the first thing we notice is the condensation of steam. If we warm only the closed end of the tube, the steam will condense to drops of water on the cooler part, and we may be able to shake out drops of water. If the experiment is repeated with wheat, barley, turnips, clover, or any other kind of vegetable matter, the same result will be obtained. Evidently, therefore, water is an abundant and important constituent of all crops.

But the importance of water to the crop is measured not only by the amount contained in the crop at any given moment. Botanical investigations have shown that, as long as a plant is alive and growing, its root-hairs are constantly absorbing water from the soil. This water ascends through the roots, stems, and branches to the leaves, from which it is evaporated into the air. This passage of water through the plant is known as transpiration. It is necessary to the life of the plant, just as the blood circulation is essential to the life of an animal. The amount of water which thus passes through a crop is enormous, and amounts to about 500 lb. for every pound of dry matter which the crop produces. Compared with this, the amount of water contained in the crop at any given moment is negligible. Evidently, therefore, the old idea of ascertaining the needs of a crop by chemical analysis was misleading. A plant is alive, and its needs are continuous. It is only by remembering this that serious mistakes can be avoided.

We must regard water as perhaps the most important factor in crop production.

Air and Light.

If we now put into a test-tube some chopped hay or other vegetable matter, which has been kept overnight in a steam oven so that it no longer contains any water, and heat it more strongly over a flame, we shall notice that two things take place simultaneously. The vegetable matter will char or blacken, and at the same time steam will be given off and condensed to drops of water on the cooler parts of the tube.

Now water consists of oxygen and hydrogen in combination, and the charring or blackening is due to the separation of carbon. The simultaneous formation of these two substances shows that the dry vegetable substance contained carbon, oxygen, and hydrogen in combination. The combination was broken up by heating, the oxygen and hydrogen recombining to form water, and the carbon being left as a black residue in the tube.

In addition to water, plants therefore contain carbon, oxygen, and hydrogen. The oxygen and hydrogen could be obtained from the water taken in from the soil. Botanists have shown that the carbon is obtained from the carbon dioxide of the air by the process of photosynthesis or assimilation. This process has been shown to take place in the leaves. The green colouring matter of the leaves, chlorophyll, absorbs the energy of light, and by means of this energy the plant's protoplasm is able to separate the carbon dioxide of the air into carbon and oxygen. The carbon is retained by the plant, being combined with hydrogen and oxygen to form starch; the oxygen is returned to the air.

This action may be crudely represented by the following equation:—

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{5H_2O} = \underset{\text{Starch}}{C_6H_{10}O_5} + \underset{\text{Oxygen}}{6O_2}.$$

Exactly how the process takes place, and what are the intermediate stages we do not know. We do know, however, that under the influence of light, green plants do absorb carbon dioxide from the air and water from the soil, and at the same time form starch in their leaves and give out oxygen, and we must note that air and light are important factors in plant growth. How important these factors are is shown by the fact that an acre of wheat contains over one ton of carbon obtained from the air by the help of light.

Ash.

To return to our test-tube. If we shake out the charre remains of our vegetable matter, put i in a crucible or on a bit of platinum foil and heat it in the open air, we shall find that it glows an the black carbon burns away, leaving a small quantity o incombustible matter or ash. The proportion of as varies in different plants and in different parts of th same plant, but the constituents of the ash are always th same, namely, iron, lime, magnesia, potash, soda, phosphate, sulphate, chloride, carbonate, and silicate. I addition to these constituents, some plants contain traces of manganese, lithia, bromide, and iodide.

The proportions in which the ash constituents are present vary greatly. In seeds, the ash usually contains a larg proportion of phosphate, whilst potash and silicate tend t accumulate in the stems and leaves. The proportion o lime in the ash varies in different plants, some plant containing much lime and others comparatively little.

The ash constituents as a whole form only a small proportion of the crop, usually only about 5 per cent. of its dr weight, or even less; most of them are, however, absolutel essential for growth. This is shown by growing seeds i pots of sand to which all the separate ash constituent except one are added in suitable proportions. Such experiments show that growth will not continue in the absenc of iron, lime, magnesia, potash, phosphate, sulphate o chloride, and these substances must therefore be regarde as essential constituents of plants. Analyses of soils show that typical soils contain sufficient of most ash constituent to supply the requirements of ordinary crops. This, however, is not so in the case of lime, potash an phosphate, and these substances are therefore important factors in determining th productivity of a soil. This conclusion is confirmed by th

Lime, Potash, Phosphate.

results of field experiments which show that on many soils the productivity can be increased by the application of manures containing these substances.

One more substance must be added to this list. If a little dried plant substance is mixed with soda-lime and heated in a test-tube, ammonia is given off and can be recognised by its smell, and by its power of turning red litmus-paper blue. Now ammonia is a compound of nitrogen and hydrogen, and the plant must therefore contain nitrogen.

Nitrogen.

In the early days of Agricultural Chemistry, the source of plant nitrogen was a much debated question. Some of the earlier experimenters assumed that since the air contains 80 per cent. of nitrogen, plants obtained their nitrogen from the air by the agency of their leaves. This was shown to be untrue in the case of cereals and some other plants by several investigators, who found that the total weight of nitrogen in the full grown plant did not exceed the sum of the nitrogen contained in the seed and that contained in the pot of sand in which it was grown. The question was complicated by the results obtained with beans and peas by other experimenters, who found that the full grown bean or pea plant contained far more nitrogen than the sum of that in the soil and that in the seed, and justly concluded that the balance must have come from the air. The question is now finally settled, and we know that in no case does a plant obtain its nitrogen directly from the air, though beans, peas, and other members of the order leguminosæ are able to get nitrogen from the air indirectly through the agency of microbes growing in nodules on their roots.

This conclusion has been abundantly confirmed by the results of field experiments. At Rothamsted, for instance, after over 70 years of continuous field experiments, the yield of wheat on the continuously unmanured plot is only 12 bushels per acre, whilst the plot continuously manured with ammonia salts yields on the average 21 bushels. Evidently, therefore, we must add nitrogen to the list of factors which are important in determining the productivity of the soil.

Quantitative analysis of soils show that in the average arable soil the proportion of nitrogen is usually about ·1 per cent. An average arable soil to the depth of nine inches is found to weigh about 3,000,000 lb. per acre. The weight of nitrogen contained in the top nine inches of soil is, therefore, about 3,000 lb. Since the roots of ordinary crops penetrate the soil to a depth of two, three, four, or even five or six feet, that is to say from three to eight times nine inches, we may safely conclude that an ordinary soil contains from 5,000 to 6,000 lb. of nitrogen within reach of the roots of most ordinary crops.

An average wheat crop of 33 bushels of grain and 25 cwt. of straw per acre contains in the grain 36 lb. of nitrogen, and in the straw 10 lb., or a total of 46 lb. per acre. Evidently, the total amount of nitrogen in an average soil is sufficient to grow, say, 100 average wheat crops in succession. And in spite of this 20 lb. of nitrogen applied to a wheat crop in the form of nitrate of soda or sulphate of ammonia will always increase the yield, frequently by 10 or 20, or even 30 per cent.

Microbes.

Evidently the nitrogen contained in nitrate of soda or sulphate of ammonia is in some way different from the nitrogen contained in the soil, for 5,000 lb. of soil nitrogen produces say 30 bushels of wheat, whilst 20 lb. of the nitrogen of nitrate of soda produces a further six bushels. In other words it takes nearly 170 lb. of soil nitrogen to produce one bushel of wheat, whilst 3½ lb. of the nitrogen of nitrate of soda will give the same result. Now it has been found by botanists that plants absorb from the soil only those substances which are soluble in water. Both nitrate of soda and sulphate of ammonia dissolve readily in water and are, therefore, available for crops. If we shake up a weighed quantity of soil with water and then filter off the soil and analyse the solution, we find that of the very large amount of total nitrogen contained in the soil only a very small amount has dissolved in the water, and further examination shows that this small amount which has dissolved is chiefly calcium nitrate with a very little ammonia. These facts explain the difference between the soil nitrogen and nitrate of soda nitrogen in their effect on the crop. Nitrate of soda nitrogen is soluble in water and therefore available to the crop. Soil nitrogen is for the most part insoluble in water and therefore not available to the crop.

Microbes.

But some of the soil nitrogen must be available, for the plot at Rothamsted which has been continuously unmanured for nearly 80 years still continues to produce about 12 bushels of wheat every year. Bacteriological investigation of the soil has shown that it contains several millions of microbes in every gram. Among these are microbes which feed upon the humus of the soil, and in doing so convert its store of insoluble nitrogen into ammonia. Others feed upon the ammonia and convert it into nitrates, and it is upon the nitrates that our crops feed. Our crops are therefore dependent upon these two kinds of microbes for the preparation of nitrates on which they may feed. We must therefore add the presence of certain kinds of microbes as another important factor in determining the productivity of the soil.

These microbes have been found to require certain definite conditions for their proper growth. They require plenty of air in the soil, the soil must be fairly warm, and it must contain a good supply of calcium carbonate. Air in the soil is dependent on cultivation and drainage. These operations also considerably affect the warmth of the soil. The supply of calcium carbonate can be maintained by manuring and has already been mentioned as a crop requirement. A well aerated and warm soil is also beneficial to crops, and we must therefore certainly include cultivation, drainage and soil temperature among our list of important factors of productivity.

Drainage and Cultivation.

We might continue almost indefinitely this discussion of the factors of productivity, but it will serve no useful purpose to go into detail here. Details will come later. There are, however, two very important factors which must be mentioned. It is a matter of common knowledge that wheat grows best on a heavy soil, *i.e.* a soil containing a fair proportion of clay. Barley and swedes, on the other hand, are best suited for lighter soils which contain but little clay and much sand. Almost every crop prefers soil of a certain definite type, and productivity is largely influenced by selecting crops which are well suited to the type of soil.

Soil Type.

After the farmer has given his best attention to all these factors, after he has chosen his crops to suit his soil, drained and cultivated his soil in the most approved manner, and manured it to suit both his crops and the microbes which prepare their food salts, the actual result he may achieve depends upon a number of conditions which are beyond his control and may be classed together under the single word climate. Although climate cannot be controlled, the science of meteorology has done so much to systematise our knowledge in various directions which are useful to the farmer,

Climate.

that no discussion of the factors of productivity is complete without the inclusion of the outlines of meteorology.

It is clear from the above discussion that agricultural chemistry as understood to-day does not confine its enquiries to the analysis of soils and the prescription of manures. It attempts to discover the general principles of crop production, and though its methods are mainly those of chemistry, it does not hesitate to avail itself of the assistance of the allied sciences, botany, bacteriology, physics and geology.

Chemical analysis will enable us to ascertain if a soil is deficient in lime, potash, phosphate or nitrogen, and to find out the most economical way of making good the deficiency by manuring. But we recognise that manuring is not a panacea for all the failings of the soil. If the rainfall is deficient or the structure of the soil allows the rain to go to waste, manuring will not ensure a crop. We must grasp the idea that the productivity of a soil is limited by the factor which is most deficient. Thus if a soil can only supply nitrogen enough to grow 20 bushels of wheat, the crop will be limited to 20 bushels, although rainfall, air, light, lime, potash, phosphate, microbes, cultivation and climate were all up to the 50 bushel standard. A deficiency of this kind is easy to correct. In such a case the use of say 1½ cwt. per acre of nitrate of soda will increase the crop to 50 bushels, and its use will be profitable, for 1½ cwt. of nitrate of soda costs only 35s., and the increase produced, 30 bushels of wheat, is worth about £17.

Suppose, however, the deficient factor is bad drainage, and that this limits the crop to 20 bushels. Although the other factors may be at the 50 bushel level, the crop will remain at 20 bushels, and to spend 35s. per acre on manures is to waste that sum of money. The field must first be drained, and this may involve a serious outlay of capital.

In the following chapters the various factors of productivity will be discussed more fully, and methods will be described by which they can be investigated.

Successful crop production depends on the discovery of the factors which limit the productivity of the soil in any district, followed by the application of appropriate methods of improving those factors which are found to be deficient.

CHAPTER II.

SAMPLING THE SOIL. MECHANICAL ANALYSIS. SOIL TYPES.

Principles of Sampling.

One of the chief troubles of the agricultural chemist is the difficulty he meets with in obtaining representative samples of the various materials which he is called upon to investigate. This difficulty is well exemplified in the case of soil. It is due to the fact that soil is not a homogeneous material, that is to say, all the particles of which it is composed are not alike. Usually the soil of a field is obviously not uniform throughout.

Frequently the soil on the surface is different from that a few inches below the surface. No useful results therefore can be obtained by analysing a sample of soil unless that sample is so taken that it may represent the bulk of the soil in the field or district. The guiding principle in soil sampling is to take a sample from an area which is reasonably uniform, and to take the sample in such a manner that it represents the whole bulk of the soil on that area.

To ascertain that the area which it is desired to sample is uniform it is usual to walk over it and to dig trial holes at several places, taking careful observations of the appearance of the soil. To take a representative sample two methods are commonly used. The first method is carried out by driving into the soil a strong steel box or cylinder of known sectional area. The sides of the box or cylinder are marked in inches, and it is driven into the soil to a depth of 9 inches unless there is some good reason for not going so deep. After driving it to the desired depth, the surrounding soil is removed, a steel plate is pushed underneath, and the cylinder or box lifted up so that the soil it contains can be transferred to a small sack for transport to the laboratory. The advantage of this method is that it enables the operator to take a sample of known area and depth, from the weight of which the weight of an acre of the soil can be calculated. Thus:—

Rothamsted Method.

The sampling cylinder used at the School of Agriculture has a sectional area of ·482 sq. feet, which is almost exactly one-ninety thousandth of an acre. A sample of sandy soil 9 inches deep taken with this cylinder weighs 33 lb. The soil on an acre 9 inches deep therefore weighs 33 × 90,000 lb. or practically 3,000,000 lb. A sample of clay soil taken in the same cylinder to the same depth weighs 28 lb., or 28 × 90,000 lb. or practically 2,500,000 lb. per acre. These figures are useful because they enable the analyst to convert his percentages of nitrogen, phosphate, potash, etc., into weights per acre.

Weight per Acre.

But while very valuable for this reason, the method possesses certain defects, the chief of which is that however carefully the spot is selected before taking the sample, the operator may have the bad luck to select a spot which for some reason or other is abnormal. For instance a manure bag may have been placed there last year, a hay cock may have stood there for some time, etc.

The Augur Method.

To obviate these mischances, many experiments nowadays use what is known as the Augur Method. The essence of this method is the taking of a large number of small samples scattered evenly over the area under investigation. This is rendered possible by using an instrument like an Augur, by means of which cores are bored out of the soil. Ten to twenty cores are taken in this manner, and mixed together to form a composite sample. This is undoubtedly the best method for obtaining a really representative sample.

Box Method.

To take a sample in the absence of both the above instruments, as for instance in the case of a farmer who wishes to send a sample of soil to a laboratory for analysis, the best method is to cut a square block of soil by four cuts of a spade, and to dig away the surrounding soil so as to leave the block standing in its original position. A wooden box is then inverted over the block, the spade inserted below the block so as to lift out together both box and soil. The box is then turned right side up and the lid nailed on. The farmer must then label the box with full particulars before forwarding it to the laboratory. The sample should be not less than 6 inches square, and 9 inches deep.

This method possesses the special advantage of preserving the soil more or less undisturbed, which enables the analyst to make many observations as to depth of cultivation, etc., which he would have made in the field if he had been there.

Preparation of Sample.

On arrival at the laboratory the soil must be prepared for analysis. The first step is to spread out the sample on large sheets of brown paper in a warm room, so that it may become air-dry. Certain experiments, however, should be made on parts of the sample in its natural condition. These will be described in their proper place. When air-dry the sample is crumbled up as much as possible, thoroughly mixed, and a kilo weighed out for further treatment. The rest is usually labelled and preserved for further reference.

Definition of "Stones."

The next step is to separate the soil from the stones, and before this can be done it is necessary to define what is understood by the term "stones." Now stones are of all sizes, and there is no scientific reason for fixing any particular limit of size above which the particles of which the soil is composed should be called stones. But it is necessary to draw a line somewhere, and it is most desirable that every analyst should draw the line at the same limit: otherwise the figures obtained by different analysts would not be comparable. To achieve this desirable end the soil analysts at most of the agricultural institutions in the United Kingdom have come to an agreement or convention in this and many other such points which will be referred to later. The convention as to stones is that those portions of the soil are called stones which will not pass through a sieve with round holes $\frac{1}{8}$ inch or 3 mm. diameter.

Separation of "Stones."

Working on this convention, the stones are separated by rubbing the soil in a mortar with a wooden pestle and sifting it on a sieve made of perforated zinc with holes $\frac{1}{8}$ inch in diameter. The stones which refuse to go through are then washed with water, dried, weighed, and their percentage calculated and recorded. It is assumed that the plant can extract no food salts from those stones and they are discarded in all subsequent experiments and calculations.

The portion of the sample which passed through the sieve is preserved for further experiments and is labelled coarse soil.

For certain experiments it is necessary to have more finely ground material. To prepare this 100 grams of the coarse soil is weighed out and ground repeatedly in a mortar until the whole of it passes through a sieve made of perforated zinc with holes of 1 mm. or $\frac{1}{25}$ inch in diameter. This is then bottled and labelled fine soil for chemical analysis.

The First Factor of Productivity.

Having obtained a representative sample and prepared it for examination, we are now in a position to consider our next step. In the last chapter the factors which govern the productivity of a soil were discussed, and it is necessary to choose which of them we will first investigate. The first thing a farmer ought to do is to grow crops which suit the type of soil which he is farming. Logically, therefore, the first point to investigate is the type to which the sample belongs.

Soils and Crops.

It has long been recognised that certain crops grow best on certain types of soils, wheat and beans for instance flourish on clay soils, barley and swedes on sandy soils, sainfoin on chalk soils, and potatoes on light loams, but it was not until the idea of soil types was developed by Whitney in America that our knowledge took systematic shape.

Whitney's Survey Method.

Whitney, when he was professor of Geology at the Maryland State College, made a survey of the soils and crops of Maryland and several neighbouring states, and found that certain definite types of natural vegetation, and the successful cultivation of certain farm crops, were invariably developed on soils of definite structure, the structure of the soil being defined by the proportions in which particles of various size were present.

After the publication of this work, Whitney was made the head of the Bureau of Soils of the American Department of Agriculture, and in this capacity was able to extend his survey methods to the whole of the United States. His work has definitely established the close connection between the size of the particles of a soil and the cropping for which the soil is best adapted. The survey method has been applied in England by Hall and Russell in the South-Eastern Counties, by Newman in Norfolk, by Robinson in Shropshire, and is rapidly extending. There is no doubt about the usefulness of the results which have been obtained. There are now on record the relative sizes of particles of which some hundreds of English soils are composed together with the cropping for which each soil has been found suitable. If we can determine the sizes of particles present in our sample and compare our results with these we shall be able to gain much useful information.

British Surveys.

For investigating the size of the particles we must obviously take the coarse sample in which they have not been reduced in size by grinding, and before we go further we must find the percentage of water and organic matter which it contains. For this purpose a crucible is weighed. About 5 grams of soil is put into it and it is weighed again. The crucible and soil are then kept over night in a steam oven. From the loss of weight which is due to the evaporation of water from the soil the percentage of water in the soil can be calculated. The percentage of organic matter is now found by heating the crucible and soil over a flame, stirring the soil with a stiff copper wire. The soil first turns black as the organic matter chars. Gradually the black colour disappears as the organic matter burns away. Finally the soil becomes red from

Estimation of Water and Organic Matter.

the presence of iron oxide, the red colour of which had been masked by the brown organic matter. When the soil is quite red, the crucible is cooled and weighed. From the loss in weight the percentage of organic matter is calculated.

Mechanical Analysis.

We can now undertake the separation of the mineral particles of the soil, but, before doing so, it is necessary to remove the calcium carbonate which possesses the power of making the smaller mineral particles stick together. For this purpose we weigh out 10 grams of the coarse soil, put it in a beaker, and pour on it 100 c.c. of dilute hydrochloric acid (N/5, or thereabouts, is the proper strength). The soil is allowed to remain in the acid for an hour, during which time it is stirred occasionally. It is then poured into a filter and washed until the washings are no longer acid to litmus-paper. This treatment completely removes the calcium salts from the soil, and makes it possible to separate the smaller particles.

The soil is now washed off the filter paper on to a small sieve made of brass wire gauze with 100 meshes to the linear inch. Allowing for the thickness of the wire, the meshes are ·2 mm. square. A stream of water from a wash-bottle is now directed on to the soil, which is rubbed with a finger tip in the stream of water until the water no longer comes through muddy. The sieve and its contents are now dried in the steam oven, the contents transferred to a weighed crucible and ignited to burn away organic matter which has been separately determined. Finally, the crucible and ignited particles are weighed again. Subtracting the weight of the crucible we get the weight of the particles. These particles had passed the 3 mm. sieve, but were retained by the ·2 mm. sieve. Their size must, therefore, lie between these rather

Gravel and Sand.

wide limits. It is usual to sift them on a 1 mm. sieve, and to weigh separately the fraction which is retained by the sieve and that which passes through. The former, smaller than 3 mm. and larger than 1 mm., is called fine gravel; the latter, smaller than 1 mm., but larger than ·2 mm., is called coarse sand. The percentage of each is worked out from their weights and recorded under the above names.

The muddy water which passed through the fine wire sieve contains all the particles under ·2 mm. in diameter. It is impracticable to separate these further by means of sifting, but they are easily separated by taking advantage of the fact that the rate at which particles settle through water varies according to their size.

Clay.

The muddy water is put into a beaker, a little ammonia added to it, and the particles rubbed up and thoroughly stirred with a pestle made of a glass rod stuck into a half-bored rubber cork. Water is added until the depth is 8·6 cm. It is found that all the particles except the clay settle through this depth in 24 hours. At the end of this time the liquid, which is slightly muddy with clay, is poured off from the sediment.

One such treatment, however, does not effect a complete separation of the clay. It is necessary to stir up the sediment again with ammonia, to add water to a depth of 8·6 cm., stirring again, and to pour off the floating clay again after 24 hours. This treatment must be repeated daily until the liquid after standing 24 hours is practically clear. The muddy liquid which has been poured off is now acidified with hydrochloric acid, which combines with the ammonia, making ammonium chloride. This sal causes the clay particles to form aggregates, or crumbs which very soon settle. The clear liquid is then poured off, the sediment washed into a weighed dish, dried and weighed. Its percentage is calculated and entered as clay.

Before drying, a drop of the muddy liquid is placed on a glass slide and examined under a high power of the microscope with a micrometer in the eye-piece. It is found that the particles are less than ·002 mm. in diameter.

Fine Sand and Silt.

The sediment from which the clay was poured off contains particles less than ·2 mm. and greater than ·002 mm. in diameter. It is separated into three fractions. The first fraction, called fine sand, whose particles are between ·2 and ·04 mm. in diameter, is separated by settling through 7·5 cm. of water in 75 seconds. The second fraction settles through the same depth in 750 seconds, or 12½ minutes. It is called coarse silt. Its particles are between ·04 and ·01 mm. in diameter. The third fraction settles through the same depth in 7,500 seconds, or 2 hours 5 minutes. It is called fine silt, and its particles are between ·01 and ·002 mm. in diameter.

Summary.

The sample of soil has now been separated into six fractions, which differ in the size of their particles. In addition to these fractions, the percentage of stones was estimated in the original sample, and estimations have also been made of water and organic matter. The results are finally recorded in the table overleaf. The loss in ordinary soils should not be more than 2 or 3 per cent. In soils containing much chalk it will, of course, be greater.

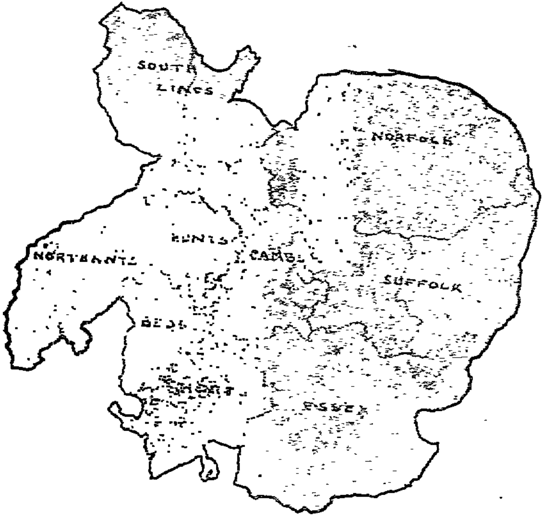
British Soil Types.

Such a table gives an excellent idea of the structure of a soil, and naturally leads us up to two further points—How are we to connect the structure of the soil as revealed in such a table with the type of farming for which it is best suited?

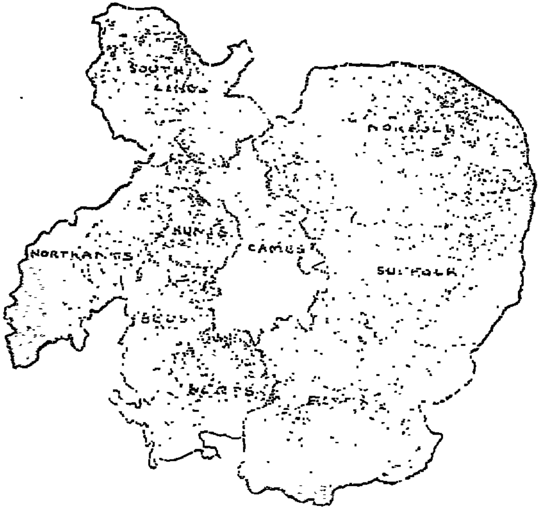
What are the properties of the various fractiona
stituents of the soil, and how are they connected wit
ductivity? As we have decided to study soil types
we will deal at once with the first point.

	Percent
Stones, in original sample	
Soil, after removal of Stones :—	
Water	
Organic matter	
Fine Gravel, particles between 3 and 1 mm. ...	
Coarse Sand, ,, ,, 1 and ·2 mm. ...	
Fine Sand, ,, ,, ·2 and ·04 mm...	
Coarse Silt, ,, ,, ·04 and ·01 mm.	
Fine Silt, ,, ,, ·01 and ·002 mm.	
Clay, ,, under ·002 mm.	
Loss in analysis, Calcium Carbonate, etc. ...	
Total, exclusive of Stones	100·0

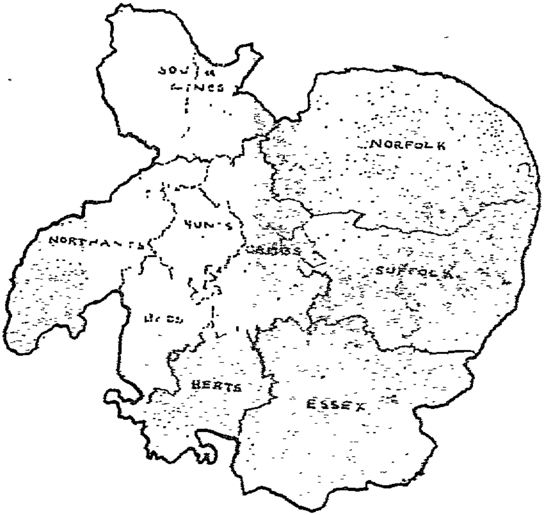
For many years the Ministry of Agriculture
collected annually figures giving the area of each
portant crop grown in each parish throughout the cou
A good general idea of the distribution of crops is
tained by marking on a blank map, giving only parish
lines, a dot for each 10, 20, 25, or 50 acres of the
grown in the parish. When the map is finished, the
give the distribution of the crop, as shown in Maps 1
pages 21 and 22. It will be noticed that the oat crop, sh
in Map 1, is evenly distributed over the entire area. Th



MAP 1.
DISTRIBUTION OF OATS IN THE EASTERN COUNTIES.
1 dot = 10 acres

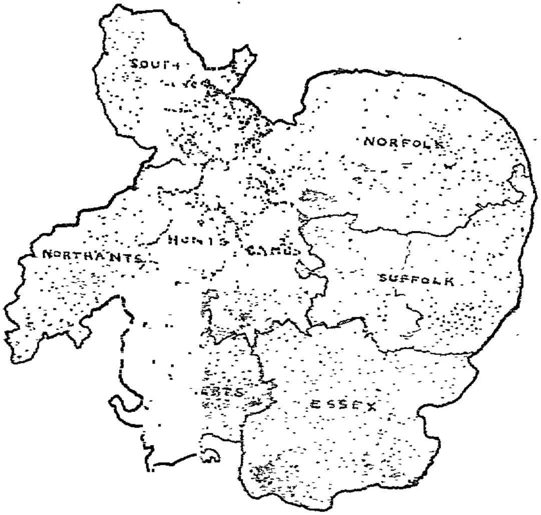


MAP 2.
DISTRIBUTION OF WHEAT IN THE EASTERN COUNTIES
1 dot = 10 acres



Map 3.

Distribution of Beans in the Eastern Counties.



Map 4.

Distribution of Potatoes in the Eastern Counties.

due to two causes: firstly, that oats will grow fairly well on almost any kind of soil, and, secondly, that almost every farmer grows oats if he possibly can because he wants them to feed his horses.

In the case of wheat and beans, Maps 2 and 3, the crops are much less evenly distributed. Comparison with the geological map shows that these crops are chiefly grown on those geological formations which give rise to the heavier types of soils. This is especially so with beans. The reason why some wheat is grown on the lighter soils is probably that every farmer tries to grow enough wheat to provide straw for thatching his stacks, even though his soil may not be suitable.

In Map 4, showing the distribution of the potato crop, the scattered dots represent the potatoes grown in gardens for home consumption. The crowded dots to the west of the Wash show how potato cultivation flourishes in that area because the soil will produce a very heavy crop. The smaller crowds of dots near Norwich and the north of the Thames Estuary represent the effect of local markets.

Wheat Soils.

The soils on which wheat is most extensively grown have been sampled and analysed, and from the consideration of the results it appears that what may be called the "wheat and bean type" of soil possesses the composition shown in the table overleaf. Provided that other factors, such as rainfall and climate, are satisfactory, it should be possible, by suitable cultivation and manuring and drainage, if necessary, to grow excellent crops of wheat on soil of approximately the composition shown above. The structure of the soil, at any rate, would not be the limiting factor of productivity. If the structure of a soil on which it is desired to grow wheat differs widely from that shown in the table, then this structure might well limit the yield.

Composition of "Wheat and Bean" Soil. Boulder Clay, East Norfolk.	Percentage.
Stones...	...
Water	3·0
Organic Matter	6·6
Fine Gravel	1·4
Coarse Sand	20·0
Fine Sand	21·2
Coarse Silt	8·0
Fine Silt	0·2
Clay	16·2
Loss, including $CaCO_3$ 4·3	5·4
Total	100·0

This is very similar in some respects to the typ wheat soil mentioned by Hall and Russell in their su of the South-Eastern Counties, which has the follow composition :—

Hall and Russell's Wheat Type.	Percentage.
Stones...	
Water	
Organic Matter	
Fine Gravel	1·5
Coarse Sand	4·0
Fine Sand	24·4
Coarse Silt	22·9
Fine Silt	13·3
Clay	18·7
Total	

This type grows wheat successfully in Kent, Surrey, and Sussex, though it contains less sand and more of the finer-grained fractions than the Norfolk Boulder Clay wheat type.

Wheat, however, is not very particular as regards the structure of the soil. It is grown successfully on soils as widely divergent from the type as the following:—

Extreme Types of Wheat Soils.	Norfolk Glacial Loam.	Suffolk Boulder Clay.
Stones...	—	—
Water	1·2	4·7
Organic Matter	4·3	9·7
Fine Gravel	1·0	·8
Coarse Sand	23·7	10·7
Fine Sand	41·3	15·0
Coarse Silt	12·5	11·9
Fine Silt	7·7	13·5
Clay	7·0	26·6
Loss, including $CaCO_3$ ·13 and ·67 respectively ...	1·3	7·1
Total	100·0	100·0

The Suffolk Boulder Clay contains a high percentage of clay for arable cultivation. The clay is, however, kept in good working condition by the presence of a high percentage of organic matter and abundance of calcium carbonate.

Potato Soils.

Hall and Russell found that potatoes in the South-Eastern Counties were grown chiefly on soils derived from the Thanet sand. Their typical potato soil has the following composition. Side by side with it is shown the composition of a typical Fenland

Potato Soil. This is not peat, but what is called land, that is to say, land on the boundary between peat and the clay. It grows a large crop, which is n first-rate quality.

Potato Soils.	Hall and Russell's Type. ~~Thanet Sands~~	Cambridgeshi Skirt Land.
Stones...		
Water...		
Organic Matter		
Fine Gravel	·9	·6
Coarse Sand	20·6	·6
Fine Sand	45·2	35·3
Coarse Silt	10·8	19·0
Fine Silt	6·0	14·6
Clay	9·0	18·0
Loss, including $CaCO_3$ and respectively ...		
Total		

Sheep and Barley Soils.

Barley and turnips are usually grown in the same rot tion. The turnips are usually consumed sheep folded on the land. Land suital for this style of farming is, therefore, call "sheep and barley" land. The table opposite gives t composition of three barley soils.

The first is a typical barley soil from near the north coa of Norfolk, which grows good crops of barley of goo quality. The second is a thin soil on the chalk, also fro the north coast of Norfolk, which grows barley of exce lent quality, but cannot be relied upon to produce a goo crop. The analysis is not complete, because the soil contains nearly 30 per cent. of chalk. The method of mechanical analysis does not give good results with such soils. The third is the typical barley soil of the South-Eastern Counties. It will be noticed that barley soils contain more sand and less clay and silt than wheat soils.

Barley Soils.	Typical Sheep and Barley Soil. North Norfolk Boulder Clay.	North Norfolk Chalk. Grows good quality but small yield.	Hall and Russell's Type for S.E. Counties.

In the table on p. 26, after "Hall & Russell's Type" *delete* "Thanet Sand."

In the table on p. 27, in the heading of the last column, for "Type for S.E. Counties" *read* "Soil 122."

Clay	6·3	1·0	9·5
Loss, including $CaCO_3$, 2·6, , respectively	3·4		
Total... ...	100·0		

All kinds of soils are used for market gardening, because the possibility of growing market garden crops profitably depends more on the proximity of a good market than on the suitability of the soil. The following example is taken from the green sand near Biggleswade, where early potatoes, white turnips, cabbages, carrots, Brussels sprouts, and other vegetables are successfully grown far

Market Garden Soils.

from any large market. The soil is, therefore, presumal very suitable for such crops.

Stones	—
Water	1·2
Organic Matter	3·8
Fine Gravel	11·3
Coarse Sand	56·1
Fine Sand	10·5
Coarse Silt	7·5
Fine Silt	3·5
Clay	4·7
Loss, including $CaCO_3$ ·06 ...	1·4
	100·0

This soil, like most green sand soils, is deficient in calciu carbonate, and grows the weeds associated with sour soil *e.g.* spurrey, sorrel, stinking May weed.

Sufficient has been written to show the general idea o work of this kind. The amount of work already done o these lines in the United Kingdom is so great that it i impossible to give even an abstract of it. The abov tables, however, show the composition of soils suitable fo various types of farming as far as they are determined a present. For further information readers should consul *The Soils and Agriculture of the South-Eastern Counties*, by Hall and Russell, published by the Stationery Office.

CHAPTER III.

THE WATER SUPPLY OF CROPS AND CULTIVATION.

Importance of Water Supply.

In the last chapter we discussed the general principles of ascertaining the kind of cropping for which any particular area of soil is most suitable. Our next problem is the supply of water to our crops, for, as was pointed out in Chapter I., water is, at any rate in point of quantity, the most important factor in productivity.

Water Requirements of Crops.

The first point to consider is the amount of water required by various crops. This subject has been much studied in America, where, especially in the dry climate of some of the Western States, rainfall is more often the limiting factor in productivity than it is even in the Eastern Counties of England.

The following table gives in round numbers the average weight of water required to produce 1 lb. of dry matter by several of the more important crops. The figures given were obtained by Briggs and Schanz of the American Bureau of Plant Industries.

	Pounds of water required per lb. of dry matter produced.
Wheat	500
Barley	550
Oats	600
Clover	800
Lucerne	800

630·24 N20 2334

It will be noticed that the water requirements of vario crops per lb. of dry crop produced varies greatly. Furth more, it has been found that all varieties of the same cr do not show the same water requirement. For the prese however, we may accept the above figures.

Now the average wheat crop of the United Kingdom 32 bushels of corn per acre, and say 20 cwt. of stra Since we are aiming at high productivity we will base o calculations on a crop of 40 bushels of corn and 25 cw of straw.

40 bushels at 63 lb. per bushel weigh	2520 lb.
25 cwt. ,, ,, ,, ,,	2800 lb.
Total produce of one acre of wheat	5320
Deduct 14 per cent. for moisture	745
Total dry matter per acre	4575

4,575 lb. dry matter produced at 500 lb. per lb. = 2,287,000 lb., or, in round numbers 1,000 tons of water. good crop of wheat therefore requires at least 1,000 ton of water per acre.

Water Requirements and Rainfall.

Now the water supply of the crop comes ultimately fro the rainfall, unless of course the crop i irrigated, which is rarely the case in th United Kingdom. Rainfall is measured i inches, an inch of rain being the amoun required to cover the surface of the land to the depth o one inch. It is easy to calculate the weight of rain required to cover an acre one inch deep. It is in round numbers 100 tons. A good wheat crop therefore requires 10 inches of rainfall. This is the amount which actually passes through the plants.

In the chief wheat growing districts of England the annual rainfall is in the neighbourhood of 25 inches, and in some districts of the Eastern Counties as low as 20 inches. Only about half of this rain falls during the period when the wheat is actively growing, so that the crop needs practically all the rain which falls during its growing period. This is the case too with other crops. When it is recognised that much of the water which falls as rain flows off the surface of the land by way of ditches, brooks, and rivers to the sea, without ever penetrating the soil, and since it is also common knowledge that a considerable amount of water evaporates from the surface of the soil without in any way helping the crop, it at once becomes obvious that the supply of water to the crop is likely in many cases to be the factor which limits productivity. This is certainly the case in the arid Western States of America, and in many parts of India and Australia, and it is frequently true in the Eastern Counties of England.

Water in the Soil.

Having seen that rainfall is often likely to limit the yield of our crops, we can now turn to the practical question of studying the methods by which the maximum proportion of rainfall can be made available to our crops. Before we can proceed with this enquiry, however, it is necessary that we should learn a number of important facts about the state in which water exists in the soil. For this purpose we must make a series of experiments.

Density of Sand.

If we weigh 100 grams of coarse sand such as was separated from the soil by the wire sieve in the last chapter, and pour it into a measuring cylinder, we shall find that after gently tapping the cylinder to make the sand particles settle, the 100 grams of sand will occupy a volume of about 67 c.c. The apparent density of the sand is therefore $\frac{100}{67}$, or, almost exactly 1·5 grams per c.c.: we say apparent density because the volume of 67 c.c. was filled partly by the

actual particles and partly by the air contained in t
spaces between the particles. If now we pour the 1
grams of sand into a second measuring cylinder contai
ing 100 c.c. of water, the sand will fall through the wat
but the air will not do so, and the level of the water
the cylinder will be raised by the volume of the particl
only. The water will be found to have been raised to 140 c
The volume of the sand particles is, therefore, 140 − 1
= 40 c.c. The true density of the sand particles
therefore, $\frac{100}{40} = 2·5$ grams per c.c., and of the 67 c
originally measured, 40 c.c. was occupied by the particl
and 27 c.c. by the air spaces between the
The air spaces in coarse sand therefo
amount to about 40 per cent. of the volu
of the sand.

Air Spaces in Sand.

Before leaving this experiment we should make o
more observation. If we notice the level of the top of t
sand which has settled through the water, we shall fi
that the sand occupies 67 c.c., the same volume as th
which it occupied when it was measured dry. From th
we conclude that sand does not change in volume wh
wetted. When the sand is under water the 40 per cent.
spaces are still there but they are now filled with wat
instead of air.

Porosity of Sand.

Another experiment will show the importance of the
spaces. Loosely plug the neck of a funn
with a pledget of glass wool. Pour a fe
drops of water on to the wool and tap t
funnel until no more water will drain away. Pour in
the funnel 100 grams of sand and tap the funnel to ma
the sand settle. Now pour on to the sand 100 c.c.
water. The water will find its way into the spaces betwe
the sand particles almost at once, and in a very short ti
it will begin to run through the sand and to drain fro

the funnel. Stand the funnel in a measuring cylinder to collect and measure the drainage. Tap the funnel from time to time to shake the drops of water from the neck. When no more water drains through read the volume of the drainage, it will probably be about 80 c.c. Subtracting this from the 100 c.c. of water poured on to the sand, it appears that the sand has retained 100 – 80 = 20 c.c., *i.e.* 30 per cent. of the volume of the sand.

We can now tabulate the composition by volume of sand saturated with water; it will be:—

Sand particles	60	per cent.
Water	30	,, ,,
Air	10	,, ,,
	100	

Air in Saturated Soil.

When heavy rain falls upon a soil containing a large proportion of coarse sandy particles, the water is not lost by running off the surface, but finds its way into the comparatively large spaces between the particles. Such a soil will retain about 30 per cent. of its own volume of water. The excess of water above this will percolate through the soil into the subsoil and may be carried away in the drains if there are any. But the spaces in such a soil are considerably more than 30 per cent. of its volume, in fact 40 per cent. Ten per cent. of the volume of the soil is, therefore, still occupied by air, and this is important for both plant roots and microbes require air as well as water.

Water-logged Soil.

This is the course of events in a sandy soil with good drainage. If the subsoil is impervious and there are no drains, or if the drains are blocked, the water will fill all the spaces to the exclusion of air, and the soil will become water-logged.

If this happens there will be no air to supply oxygen plant roots and microbes, and healthy growth will impossible. This is one of the reasons why good draina is so important.

Capillarity.

Now it is a matter of common knowledge that wat like any other substance is pulled downwar by the force of gravity. Why then does t sand hold water and prevent the whole of the wat which falls upon it from running through it? St another series of experiments is necessary to investig this problem.

Take half-a-dozen pieces of glass tube varying in d meter from say 1 cm. to the finest capillary. Clamp th so that they stand vertically with their lower ends dippi in a dish of water, which should be coloured by dissolvi in it a little potassium permanganate to make it mo readily visible. Note that the water stands at a high level in all the tubes than it does in the dish, and furth that the narrower the tube the higher it rises. This is important point and should be confirmed by a seco experiment.

Thoroughly clean two sheets of glass, for instance, tw disused half plate negatives. Place them side by side that they are in direct contact at one end but separated a match stalk at the other. Fix them in this position a rubber band or a piece of string, and stand them in dish of coloured water. Note that the water rises to the slit between the two sheets of glass, and that whilst rises only a very short distance where the slit is as wi as the match stalk, it reaches the top of the sheets whe they are in contact.

Water will evidently rise to fill a narrow space, and t height to which it rises does not depend on the shape the space but upon its narrowness.

Capillarity of Sand.

Now we have seen that there are spaces in sand. Another experiment will enable us to find if water will rise to fill them. Take a wide glass tube, say about half-an-inch wide and one foot long. Tie over one end of it a piece of fine muslin or coarse linen. Weigh the tube thus prepared. Fill it with sand and weigh it again. The increase in weight will give the weight of the sand. Since the apparent density of sand is 1·5, the weight divided by 1·5 will give the volume. Thus, weight of sand = 60 grams: 60 ÷ 1·5 = 40 c.c. Now clamp the tube filled with sand so that it stands vertically with its lower end just touching the surface of water in a dish. Note that the water at once begins to rise in the sand and that in a short time the sand is darkened by the water throughout its length. When this has taken place remove the tube from the clamp, wipe the water from the lower end with a piece of filter paper and note that water does not drip from the tube. The water has evidently risen to fill the spaces in the sand and is held there against the pull of gravity.

Now weigh the tube containing the wet sand. It will be found to have increased in weight by about 10 grams, therefore 40 c.c. of sand has raised from below 10 grams of water, or 25 per cent. of its volume.

When we poured water into a comparatively shallow layer of sand in a funnel, we found that it held 30 per cent. of its volume of water. When the sand has to raise the water through a column of sand a foot high it only holds 25 per cent. of its volume. If we make a file scratch at the middle of the tube, and weigh each half separately, we shall find that of the 10 grams of water held in the sand about 6 grams will be in the lower half and 4 grams in the upper half; and if we calculate from these figures the composition by volume of the lower and upper halves, w shall find them to be:—

	Lower Half.		Upper Half.
Particles	60 per cent.	...	60 per cent.
Water	30 ,,	...	20 ,,
Air	10 ,,	...	20 ,,

These experiments show clearly that sand holds water virtue of the smallness of the spaces between its particl and, further, that in virtue of those small spaces, sand c raise water to a considerable height, so that water whi has percolated through the surface soil to the subsoil is n lost beyond recall. This point, however, will need furtl discussion.

State of Water in the Soil.

Now the property of water which causes it to push way into narrow spaces, even against t pull of gravity, is called capillarity, or surf tension. To explain its cause would lead too far into theoretical physics—we must be satisfied accept it as a fact for the present at any rate. We sh however, gain some useful knowledge by one more expe ment. If we cement a number of large glass marbles the surface of a glass plate, so that the marbles touch another, as shown on the annexed figure, and then cla the plate so that the glass is held vertically over a la dish, we shall have a large scale model of a thin layer soil. If now we pour over the marbles some thin da coloured oil, which flows much more slowly than d water, we shall be enabled to see what takes place w water runs into the soil.

We shall notice that as the oil finds its way among marbles it forms a skin, or film, over the surface of e marble, and these films move downwards until drops of begin to form at the lowest point of the bottom row marbles. If we continue to pour more oil on to the t these drops will increase in size until they detach themselves, and fall into the dish placed to catch them.

If we now cease pouring and leave the apparatus for a short time, the oil will finally come to rest, forming a film round the marbles.

It will be noticed that on the whole the film is thicker round the bottom layer of marbles than round the upper layers: that it is thicker at the bottom of each marble than at the top: that it is much thicker where the marbles touch each other and make narrow spaces: and that the oil does not fill the comparatively large spaces between the marbles which still contain air.

Movements of Water in the Soil.

If a pad of blotting paper is now held in contact with the upper layer of marbles, the oil will be seen to pass from the marbles to the blotting paper, because the spaces between the fibres of the paper are smaller than those between the marbles. As this takes place the films of oil round the marbles become thinner, and, if the experiment succeeds well, the accumulations of oil at the points where the marbles touch, and even the drops hanging from the bottom row of marbles, will be seen to decrease in size.

The experiment may be reversed by holding the blotting paper in contact with the bottom row of marbles, when similar movements of oil will be seen to take place—more quickly in this case because they are helped by gravity.

Now this illustration may be applied to the soil. Water is distributed through the soil as films round the particles, which are thin where the spaces are larger, and thick where the particles touch, exactly as was noticed in the case of the oil among the marbles. Just as in the case of the marbles, the water films in soil are usually thicker in the lower layers. The water in the films is capable of movement, and, as a matter of fact, is always in motion.

In the summer in dry weather water is withdrawn continuously from the surface of the soil both by evaporatio and by the transpiration of the crops. This thins th films covering the particles of the upper layers, and wat moves upwards from the deeper layers where the films ar thicker. This movement goes on as long as the weathe keeps dry. If the drought is very prolonged the store o water in the deeper layers of the soil may not suffice t maintain films up to the surface. The films in the upp layers break, the surface becomes quite dry and dust and the crop may not get enough water to maintai growth.

Tillage and Water Movements.

The causes of this state of things are—(1) deficien rainfall, (2) transpiration and evaporatio exceeding the rise of water from belo (3) insufficient store of water in the low layers of the soil. Unfortunately, the rainfall is beyond our control. Transpiration, too, cannot b checked, except by breeding new varieties of crops whic require less water per lb. of dry matter produced. Bu direct evaporation is readily prevented by the simple expedient of maintaining on the surface of the soil a layer o dry soil, which the Americans call a soil mulch. This done by surface cultivation by means o shallow ploughing, harrowing, or by th hand or horse hoe. When the surface cultivated the soil, which is, so to speak, cut off from th compacted soil below it, dries out at once and shields th moist lower layers from wind and sun. This at onc practically stops evaporation.

Surface Cultivation.

The efficacy of such surface cultivation in maintaining the store of water in the deeper layers of the soil shown by the following figures taken from an experimen by King in America. The soil of a field was sampled o the 29th of April, and found to contain 68·8 lb. of water per square foot to a depth of 4 feet. Half the field was surface cultivated immediately after the samples were taken. After a week of dry weather the cultivated and uncultivated parts of the field were sampled separately, and found to contain, where the surface had been cultivated, 68·9 lb. of water; where the surface had been undisturbed, 59·8 lb. of water; in each case per square foot 4 feet deep. Surface cultivation had evidently completely checked evaporation, whilst the undisturbed soil had lost 9 lb. of water per sq. foot 4 feet deep. This is equivalent to 175 tons per acre, or 1¾ inches of rainfall, or nearly one-sixth of the total amount of water required by a good crop of wheat.

This is perhaps an extreme case, but it serves to show the efficacy of surface cultivation in checking evaporation, and so conserving the water in the soil. It shows also that the real point of surface cultivation is rather the conservation of water than the eradication of weeds, though this is a sufficiently deserving object to make the operation worth the trouble and expense.

Autumn Ploughing.

But the store of water in the subsoil can be increased by other methods than the checking of evaporation by surface tillage. During the winter the rainfall commonly exceeds the evaporation. Consequently there is on the whole a downward movement of water from the surface to the subsoil. This can be assisted by autumn cultivation, by ploughing, for instance, so as to leave the surface as rough as possible. This is especially valuable in the case of a clay soil, which, being impervious, does not readily admit the rainfall, much of which, therefore, flows off the surface if it is smooth. If it is rough, the water is held in the inequalities and slowly finds its way into the subsoil.

In an experiment at the Wye College part of a field v ploughed up rough in the autumn, whilst the rest of t field was left undisturbed. The percentage of water the first two feet of soil at the beginning of the followi March were: autumn ploughed, 16·2 per cent.; und turbed, 15·2 per cent. This corresponds to an increase about 50 tons of water per acre in the first two feet. If t increase continued to 4 feet, as is probable, 100 tons water, or 1 inch of rainfall, would have been saved—a this is 10 per cent. of the water required by a good whe crop.

Summary.

So far we may sum up our conclusions as follows:—In dry climate, where water is often the limi ing factor in productivity, we should kee the surface well cultivated. This lets the water into tl soil in the winter, and prevents loss by evaporation in th summer. The particular types of cultivation suitable fo winter and summer are subjects for the agriculturis rather than the chemist.

These are the principles which underlie what is know as "dry farming." They are practised in the arid stat of America, in India, and in Australia, where it is foun possible to grow profitable wheat crops with a rainfall o only 10 inches—less than half the rainfall in the dries counties of the East of England. But, in addition t those principles, farmers in these arid districts resort t two other expedients for conserving soil moisture.

Subsoil Packing.

Subsoil packing consists in consolidating the deepe layers of the soil, whilst at the same time the surface is kept loose. The loose surface admits the water, and the smallness of the spaces in the consolidated subsoil holds it when it gets there. We carry out this process in England by running stock on our arable land. Small-footed animals like sheep are especially valuable in consolidating the subsoil, and this is one of the reasons why sheep are considered to be essential to the maintenance of the fertility of the light lands in the Eastern Counties. But it must not be forgotten that the benefit of this "subsoil packing" will soon be lost if the surface is not cultivated as soon as the animals leave the land.

Bare Fallows.

The second expedient of the "dry farmer" is to give the land frequent bare fallows. When the rainfall is not sufficient to grow a profitable crop every year, he grows a crop in alternate years, or two crops in three years, and he is careful to prevent evaporation by continual surface tillage when the land is fallow. Thus the rain which falls on the fallow is conserved in the subsoil for the next crop.

Rolling.

So far we have dealt mainly with the methods of conserving the rainfall so that it may be in the soil when our crops want it. But cultivation can effect another purpose. When crops are growing we try to encourage the soil to keep its moisture in the deeper layers where the wind and sun cannot reach it and the roots of the crops can. But when we have just sown seeds, and especially small seeds, which must not be put in deep, we want the water near the surface so that it can moisten the seeds and cause them to germinate.

Now we have learned that the films of water round the soil particles will move from any part of the soil where the spaces are large to any other part where the spaces are small, and we can easily make the spaces at the surface small by compressing the surface with a roller. This is usually done immediately after sowing seeds. It brings water to the surface and hastens germination. But it is a wasteful process, for when water comes to the consolidated surface much of it is lost by evaporation. As soon, therefore, as the young plants have grown large enough to l easily distinguished and made firm enough root hold, th surface should be tilled at once with harrows, horse hoe hand hoes, or in some other manner to create a soil mulc and check loss by evaporation.

General Principles of Tillage.

A proper understanding of these general principles o conserving the soil water and moving i from one layer of the soil to another i fundamental for the proper performance o the art of cultivating the soil. The subjec is of the greatest importance, yet it has not up to th present received systematic investigation in the United Kingdom. It is for this reason that we have been compelled to draw most of our illustrations from results obtained by American investigators.

The reason, no doubt, is to be found in the fact that the necessity of conserving the soil water is more urgent in countries where the rainfall is often below 10 inches than in our more favoured land, where in no district does it fall below 20 inches. Indeed it is seldom recognised in England that water supply is so generally the factor which limits productivity. If it were, we should suffer less frequently from advertisements of patent manures, inoculations, and other such nostrums, for which it is claimed that they will double the productivity of the country. It is certain that no such increase can be made in the yield per acre of cereals on the eastern side of England, except by either increasing the rainfall or breeding new races of crops which will produce their dry matter by the use of much less water than is required by varieties at present cultivated.

CHAPTER IV.

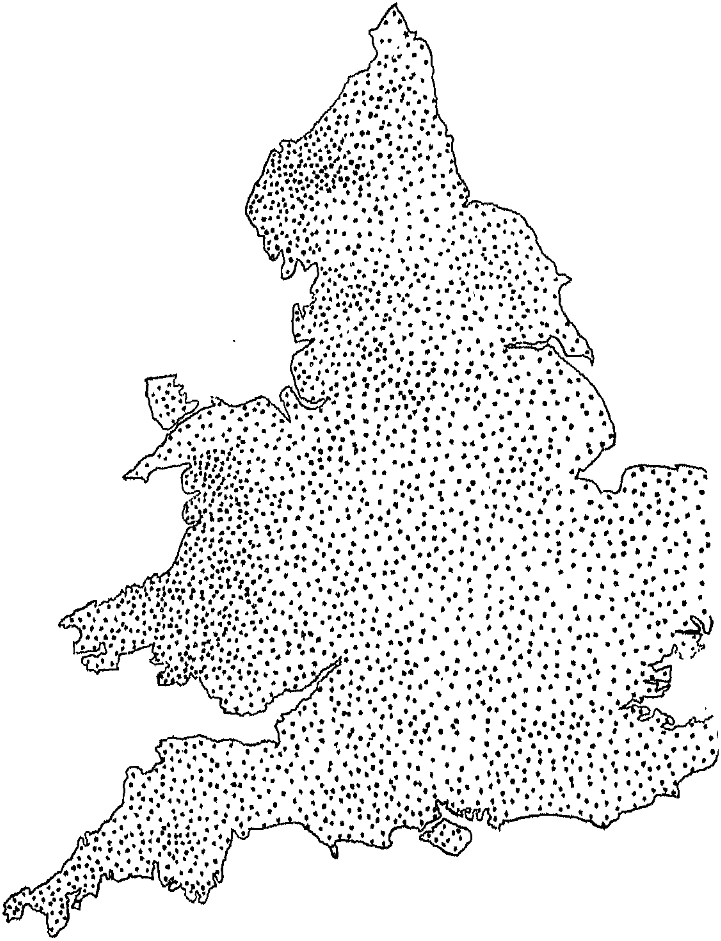
THE SUPPLY OF WATER TO CROPS. WEATHER.

In the last chapter we discussed the principles of cultivation from the point of view of their power of rendering available to our crops the water which falls as rain, and we came to the conclusion that much might be achieved by cultivation in the way of conserving the water supply.

Rainfall and types of Farming.

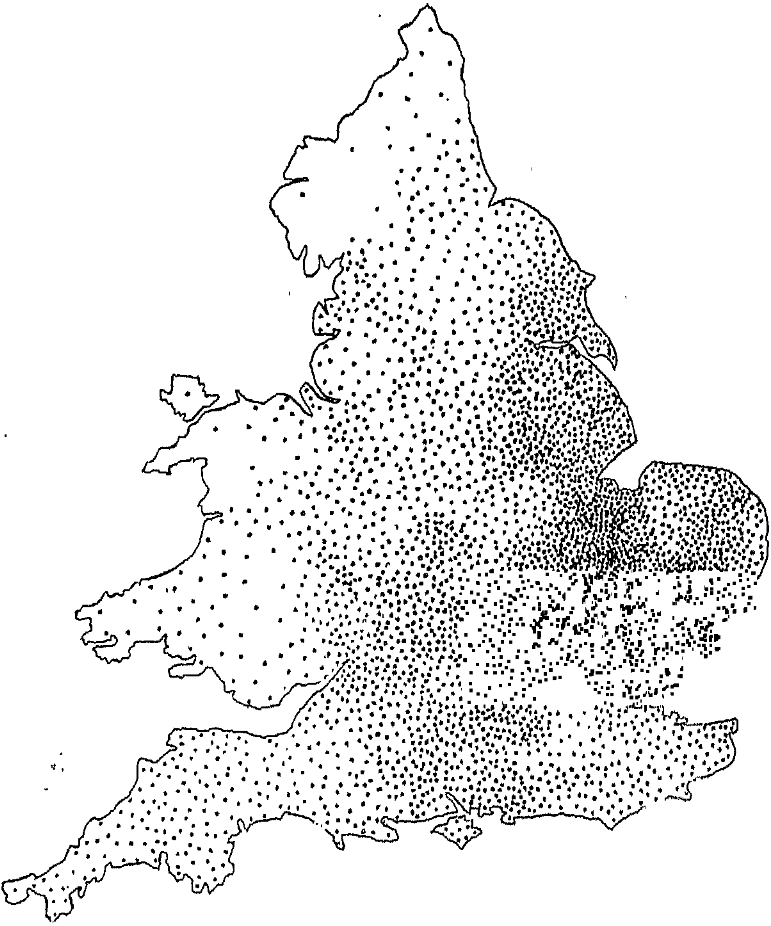
But the rainfall varies so widely in different districts that, in spite of all the efforts of the farmer to regulate the water in the soil by cultivation and drainage, the amount of water presented to the roots of crops is so widely different in different parts of the country that this factor has been in many cases predominant in deciding the type of farming. We cannot regulate the rainfall, but it is advisable that we should learn something about so important a factor, and first about its connection with types of farming.

Map 5, on page 44, shows the average annual distribution of rainfall throughout the United Kingdom. Broadly speaking the rainfall is lowest on the East Coast where it is in the neighbourhood of 25 inches, and highest in the mountainous regions of Devon and Cornwall, Wales, the Lake District, and the West Coast of Scotland where it rises to 40, 60, or 80 inches and in some districts even higher. Maps 6 and 7, pages 45 and 46, show the relation



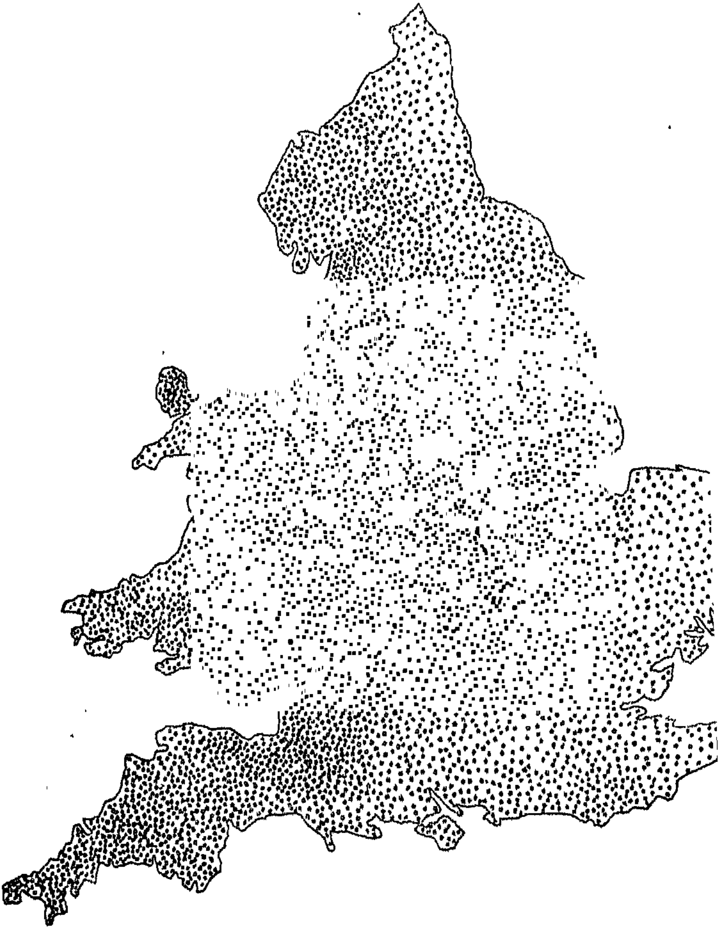
MAP 5. SHOWING DISTRIBUTION OF RAINFALL IN ENGLAND AND WALES.

[*Scale:* Number of dots in square this size ☐ = inches rainfall.]



MAP 6. SHOWING DISTRIBUTION OF WHEAT IN ENGLAND AND WALES.

[*Scale*: 1 dot = 500 acres.]



MAP 7. SHOWING DISTRIBUTION OF CATTLE IN ENGLAND AND WALES.

[*Scale:* 1 dot = 1000 Cattle.]

of agriculture to rainfall. Wheat growing, which means of course arable farming on the four course or similar rotation, is concentrated in the Eastern Counties area of low rainfall, and is hardly practiced at all in the regions of high rainfall in the West. Cattle are concentrated in the West of England and in Wales, where the rainfall is high, and concentration of cattle means grass as opposed to arable farming.

Other factors besides rainfall have probably played a part in the segregation of farming practice. Arable farming is for instance better suited to the flat lands of the East than to the hilly country of the West. Again, the altitude of much of the land in Cornwall, Devon, Wales, and Scotland is too great for many of the crops grown on arable land. Rainfall, however, must be considered the predominant factor which has determined the broad segregation of arable husbandry in the East and pastoral husbandry in the West.

Weather Forecasting.

Rainfall affects the farmer in many ways besides supplying water to his crops. It may prevent his cultivating his soil, if the soil contains much clay, and so hinder sowing. It may delay the harvesting of his hay and corn, and interfere with his operations in a variety of ways which will readily occur to readers who have heard the farmer's proverbial grumble about the weather. Now most if not all the farmer's weather troubles possess one point in common—the farmer could obviate them, or take measures to lessen the damage they may cause, if he could ascertain in advance when they were coming. Although we cannot show the farmer how to control the weather, we can at any rate tell him the general principles of weather forecasting.

Many attempts have been made to show that good and bad seasons occur in regular succession, that there are cycles of wet and dry years connected with the appearanc of sun spots and other phenomena. Sir William Beveridg has recently worked out a cycle showing a connectio between weather in different countries, prices of agricultural commodities, famines, and other happenings, bu it is not with weather forecasting of this kind that we ar concerned.

What the farmer wants to know is not the broad outlines of what the weather may be in the next year or two, but details of the weather he may expect in the next 24 or 48 hours. Fortunately the science of meteorology is now able to provide fairly reliable forecasts of this kind, and we shall now proceed to discuss the basis on which such forecasts are prepared.

The Barometer.

The barometer is the instrument whose indications are the basis of weather forecasting. This instrument consists essentially of a glass tube about a centimeter in diameter, and not less than 32 inches long. It is filled with mercury from which all the air has been expelled by boiling, and is inverted so that its open end dips into a vessel containing mercury. The mercury falls a little way from the closed top of the tube so that the difference in level between the mercury in the tube and in the open vessel is about 30 inches. At this point the mercury comes to rest. If the tube was inverted carefully so that no air was allowed to enter, the space above the mercury at the closed end of the tube will contain nothing except the merest trace of mercury vapour. Such an empty space is called a vacuum.

Let us now fix our attention on the small quantity of mercury contained in the tube where it dips into the vessel. This layer of mercury is at rest and the forces acting upon it must therefore balance each other. These forces are (1) the weight of the mercury in the tube above this level, which is measured by the difference of level between the top of the mercury in the tube and the surface of the mercury in the vessel, and it is acting downwards; (2) the pressure of the air on the surface of the mercury in the vessel which is transmitted through the mercury and acts upwards. These two forces must be equal or the mercury would move upwards or downwards. The height of the mercury in the tube therefore measures the pressure of the air.

Pressure of the Air.

The following experiment will perhaps make it easier to realise this conclusion. The barometer as described above is so arranged that the vessel containing the mercury is placed inside a glass bell-jar. If air is pumped out of this bell-jar, the mercury falls in the barometer tube. If air is now allowed to flow back into the bell-jar the mercury rises again. The height of the mercury in the tube therefore measures the pressure of the air.

The simplest way of measuring this height is to place a scale alongside the tube with one end of the scale just touching the surface of the mercury in the vessel. The difference in level of the mercury in the tube and in the vessel can then be read off directly. It will be found to be about 30 inches or 760 mm. Occasionally it may be as low as 28½ inches or as high as 31½ inches.

Many variations from this simple form of barometer are in common use, but this is not the place to describe them. If we understand how the barometer measures the pressure of the air and what its readings mean, that will suffice for the purpose we have in view, and we can now proceed to enquire what is the connection between the pressure of the air as indicated by the barometer and the approaching weather.

Barometer and Weather.

Before modern methods of meteorology were discovered we were satisfied with a very simple explanation. The density of dry air is about 1·3 grams per litre. The density of water vapour is only ·8 gram per litre, both measurements being made at standard temperature and pressure. Dry air is therefore much heavier than water vapour, consequently the more water vapour the air contains the lighter it will be, and the less will be the pressure it will exert. A low barometer would therefore indicate that the air contained much water vapour, and this in turn would indicate the probability of rain. This explanation is, however, entirely inadequate, and we must seek further, and avail ourselves of the systematic records made by the Meteorological Office.

Modern Meteorology.

These records are not the work of a single person, but of a large central organisation working in collaboration with observers at about 100 stations scattered over the country from the extreme West of Ireland to the East of England and Scotland, from the Scilly Islands to the Hebrides, together with many stations outside the United Kingdom, as, for instance, in Iceland, in Scandinavia, and in France and Spain. At several fixed hours each day each station sends by telegraph to the central office the readings of the barometer, thermometer, hygrometer, and various other instruments, together with particulars of the force and direction of the wind, the appearance of the sky, and other observations.

Weather Maps.

At the central office the particulars from all the stations are entered on a blank map, and when this is completed the headquarters staff have before them a picture of the weather throughout the British Isles and the surrounding seas and countries at the moment when the telegraphic particulars are sent off by the observers. In recent years each station telegraphs particulars to headquarters four times every day, and a map is prepared each time. The headquarters staff have therefore thousands of continuous records, each of which includes barometric and other instrumental readings side by side with particulars of the weather.

From a consideration of these records they have been able to draw definite conclusions as to the connection between the readings of the barometer and the type of weather experienced. These conclusions enable the staff to forecast the weather with considerable certainty.

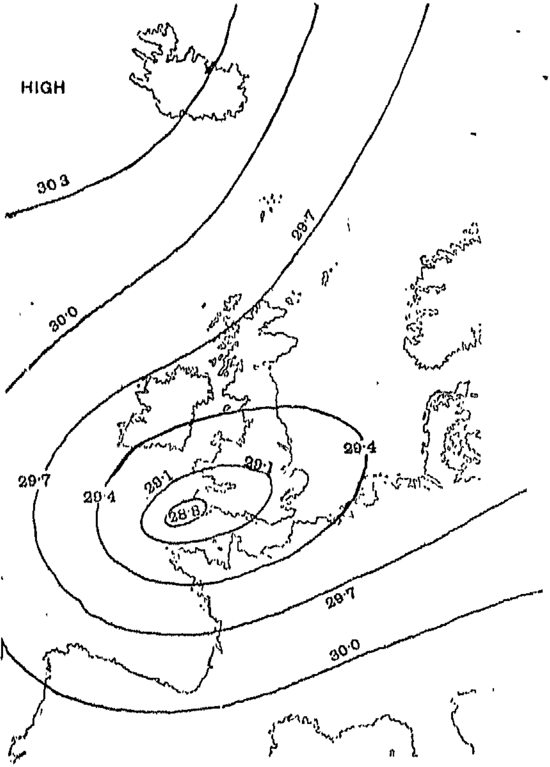
Principles of Forecasting.

To learn how this is done we must examine several typical weather maps, and first, one in which only barometric readings are included. Map 8, p. 52, was prepared by entering on a blank map the barometric readings received from all the stations, and then drawing lines joining neighbouring stations at which the same reading was observed. These lines along which the barometer gives the same reading are called isobars, or lines of equal pressure. In this map they form concentric rings round a central area of low pressure, and this distribution of atmospheric pressure is very commonly observed.

Cyclones.

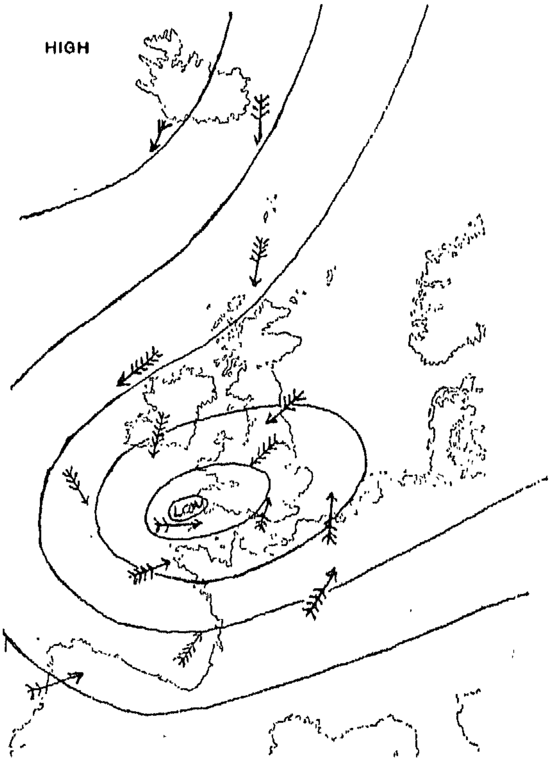
Map 9, p. 53, is identical with Map 8 but wind observations have also been entered. Notice that the wind appears to circulate round the central area of low pressure, but with a distinct tendency to turn across the isobars towards the centre. Such a pressure distribution, and its accompanying circulation of winds is called a cyclone, or a depression. It is a kind of gigantic eddy in the air, and is frequently several hundred miles across.

Experience shows that a cyclone is almost invariably associated with a certain type of weather, as shown in Map 10, p. 54. To the east of the system there is rain with a south or south-west wind. Except on the west side where

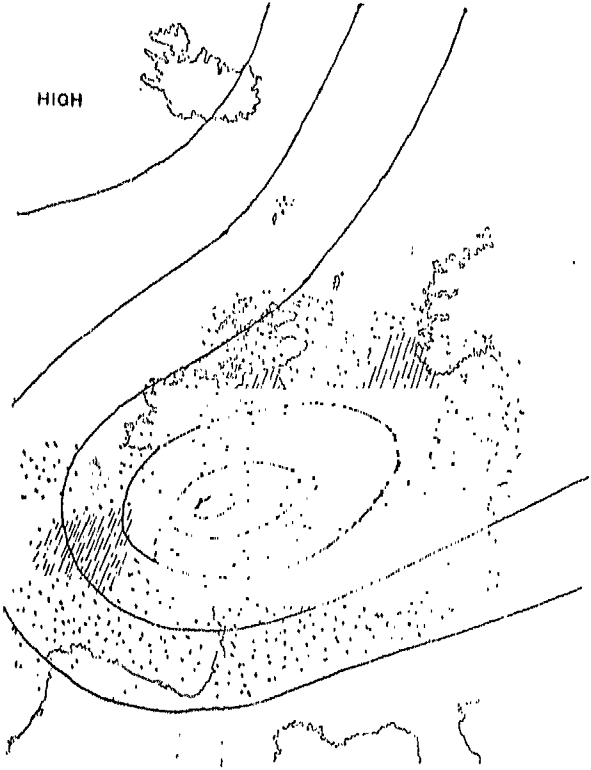


Map 8. Showing Distribution of Pressure in a Cyclone.

The black lines are the isobars.



Map 9. Showing Circulation of Winds in a Cyclone.
The arrows show the direction, and the number of feathers on the arrows show the force of the winds.



MAP 10. SHOWING DISTRIBUTION OF WEATHER IN A CYCLONE.
Dashes = rain; dots = cloud.

there are local fine areas, the rain extends all round the system, and the belt of rain is more or less completely surrounded by a circle of cloud.

Such a cyclone or depression is not stationary. It usually travels eastwards across Ireland and England or Scotland. The rate at which such systems travel is not always the same, but as a rule they cross the British Isles in two or three days. The direction of travel is usually from west to east, but it may vary from south-west—north-east to north-west—south-east. Occasionally a low pressure system travels from east to west, in which case its rate of motion is usually slow and it may be accompanied by very prolonged rain.

Succession of Weather.

As a cyclone passes any particular place an observer would notice the following succession of phenomena. First the barometer would begin to fall and clouds would appear. These would increase and change in type from high clouds to much lower rain clouds. Meantime, with a continually falling barometer rain would begin and continue for some time. As the centre of the system passed the barometer would begin to rise and presently there would be fine intervals alternating with showers. There would also be changes in the wind, but these would vary according as the observer were south or north of the centre of the system—if he were south of the centre, the wind would change from east through south to south-west and finally to west. If he were north of the system the change would be from east through north-east and north to north-west.

Barometer and Weather.

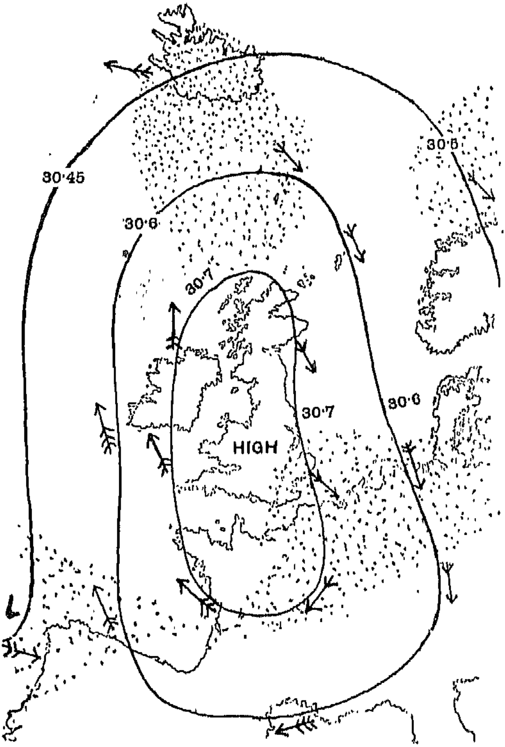
Organised observations have, therefore, established a definite connection between a certain distribution of atmospheric pressure as observed by the barometer, and the succession of weather with which it is associated. A single observer cannot predict with certainty from a single reading of his barometer what the weather will be. Such predictions can only be made by a central staff supplied from a large area with many observations from which a map can be made. The headquarters staff get their first indication of an approaching cyclone from the announcement of a falling barometer accompanied by cloud and changing wind at certain stations on the west coast of Ireland. The direction of the change of wind tells them whether the centre of the system is to the north or south of these stations, and from their experience of the direction in which such cyclones travel they can predict which part of the country is likely to be affected. Accordingly, they issue a forecast that a cyclone is approaching the west coast of Ireland, and is likely to disturb the weather during the next 24 hours, and to cause rain in the South, Midlands, or North of England or in Scotland. At the same time they can predict the probable changes in direction of the wind from the position of the centre of the cyclone, and of its force from the reported rate of fall of the barometer.

How Forecasts are made.

Six hours later, when the next set of telegrams arrive, the cyclone has probably advanced over Ireland and part of Wales and England. A new map is made which shows more definitely the path and character of the cyclone, and makes it possible to issue a more detailed forecast for the various districts of the country.

Frequency of Cyclones.

About 120 cyclones cross the British Isles every year, or on the average one every three days. This gives an idea of the extent to which the weather is dominated by this form of pressure distribution, and the importance of its recognition in weather forecasting.



MAP 11. SHOWING DISTRIBUTION OF PRESSURE, WINDS, AND WEATHER IN AN ANTICYCLONE.

Dots = cloud, mist, or fog.

Anticyclones.

It is not, however, the only type of pressure distribution which influences the weather. Sometimes the map shows a pressure distribution of an entirely different type, as illustrated in Map 11, p. 57. Here the isobars again form a series of concentric rings, but the centre is occupied by an area of high pressure. The winds again appear to circulate round the centre, but in a direction opposite to that in which they circulate round the centre of a cyclone, and they tend to cross the isobars outwards from the centre. They are also of much less intensity than is the case in a cyclone.

Such a pressure distribution is called an anticyclone, from the fact that its pressure distribution, its wind circulation, and the type of weather with which it is associated are entirely different from those characters in the case of a cyclone.

Types of Weather.
Cyclonic.

As regards the type of weather: a cyclone is a rapidly moving system and is consequently associated with changeable weather; an anticyclone moves very slowly and means settled weather. In a cyclone the isobars are near together, the pressure gradient is rapid and the winds are strong. In an anticyclone the isobars are wide apart, the pressure gradient slight and the winds of little force. A cyclone is usually associated with cloud and rain. An anticyclone usually means continued fine weather without much cloud, but frequently with mists in the summer and fog or frost in the winter.

Anticyclonic.

When the weather map shows an anticyclonic pressure distribution, the headquarters staff at the Meteorological Office are able to forecast settled weather, light winds, with little cloud and no rain, possibly mists in the summer, and fogs or frost in the winter. This type of weather will continue until the anticyclonic distribution is disturbed by a cyclone approaching from the Atlantic. Finally anticyclones do not develop as frequently as cyclones.

Other types of Weather.

Other types of pressure distribution also occur, which are less defined in character than cyclones and anticyclones. They are probably a sort of no man's land between cyclonic and anticyclonic distributions outside the British area. Their character and the type of weather with which they are associated are somewhat indefinite, and during their existence forecasting is difficult. The above account of the methods of weather forecasting is of course a mere outline, but it may serve to show that substantial progress has been made.

Special Forecasts.

Although the weather cannot be controlled, forecasting is now accurate enough to warn the farmer what weather to expect at least 24 hours ahead, and with such warning he can often make arrangements which will, for instance, mitigate the effects of rain at harvest-time. Where the daily newspaper arrives too late, or if an evening forecast is desirable at certain periods, the Meteorological Office will send telegraphic forecasts to any address by arrangement.

Other Meteorological Phenomena.

In the course of this discussion we have referred to rain, mist, fog, clouds and frost, and before closing the chapter it seems desirable to give a brief account of the causes and effects of these and other meteorological phenomena which are of importance in agriculture. Most of these phenomena are related directly or indirectly to the presence of water vapour in the atmosphere, and it will be useful to study this subject first.

Let us set up a barometer as explained above and note the height at which the mercury stands. Let us now inject a drop of water by means of a curved tube into the open end of the barometer tube, where it dips into the mercury in the open dish. The water, being much lighter than the mercury, will rise to the top. After a few minutes we will again note the height of the mercury. We shall find that it has fallen by 10 to 15 millimetres.

Water Vapour in the Air.

We will now surround the barometer tube with a wider tube which we will fill with water warmed to 40° C. We shall notice that the level of the mercury falls again, this time by about 50 mm. We will now replace the water at 40° C. by boiling water, or better still by steam, when we shall find that the mercury falls so far that it is at the same level inside the tube as it is in the open dish.

The presence of water on the surface of the mercury in a barometer tube, therefore, causes the mercury to fall, and the extent of the fall depends on its temperature. At the boiling point of water the mercury falls by the total height of the barometer. The explanation of these facts is that water gives off vapour which exerts pressure on the surface of the mercury and forces it down. At the boiling point, the pressure is equal to the pressure of the air. At lower temperatures the pressure is smaller than the pressure of the air: at the ordinary temperature of a room it is about 10-15 mm.

Boiling Point.

The point is that water at all temperatures gives off measureable quantities of vapour. This is confirmed by the common experience that water exposed to the air evaporates, or, as we say dries up, and turns into vapour which is carried away by the air.

Evaporation.

This process continually goes on in nature, water evaporating into the air, from the surface of the sea, and from ponds, lakes, rivers: also from the surface of the soil when it is wet. Plants continually send water vapour from their leaves into

Evaporation in Nature.

the air by the process of transpiration, and the respiration of animals also supplies the air with large quantities of water vapour.

It is easy to show that ordinary air contains water vapour. A flask filled with very cold water immediately gets dimmed with dew which is water vapour condensed from the air by the cold surface of the flask. This water vapour in the air is the source of clouds and rain, clouds being water vapour condensed to very small drops by cooling, and rain being formed when the small drops in a cloud run together into large ones. Dew is formed when the surface of the soil, the leaves of plants, the roofs of buildings or other surfaces become cold enough during the night to condense water vapour from the air. This happens in clear calm weather when there are no clouds to prevent the radiation of heat from the surface of the earth into space, and no wind to keep the air moving and cause evaporation. A considerable deposition of dew is therefore characteristic of anticyclonic weather as a consequence of the absence of cloud and wind.

Dew.

During such weather, the cooling may proceed so far as to cause frost, in which case, instead of dew being deposited, the deposit will be hoar frost. Frosts produced in this way frequently cause great damage to early potatoes, strawberries and other tender crops in the spring or autumn. The damage is usually greatest in the valleys, because the cooling of the surface of the ground cools the lower layers of air and in doing so increases their density. The dense cold air flows down into the valley and remains there getting colder through the night. It is cold air rather than cold soil which causes most of the damage in late spring or early autumn frosts. Attempts have been made to prevent such

Frost.

damage by lighting fires of green wood or other material which makes much smoke, the idea being that the smoke will form a cloud and prevent cooling by radiation. This precaution would of course only be used when the weather forecast predicted the possibility of frost in late spring or early autumn. Although it is theoretically good, it has not been used successfully on a large scale.

Latent Heat.

The evaporation of water from the surface of moist soil gives rise to quite another important problem. We know that when we turn water into steam by boiling, the application of heat is necessary. The quantity of heat required to convert water into water vapour is very large. It is called the latent heat of evaporation. When the dry winds of spring evaporate water from the surface of moist soil latent heat must be provided in some way. As a matter of fact it is taken from the soil and the soil is therefore cooled.

Specific Heat.

This is not the only way in which moist soil is prevented from getting warmed in the spring. If we measure into a beaker 100 c.c. of cold water and then pour into it 100 c.c. of boiling water, we shall find that the mixture will have a temperature of about 65° C. If we now measure 100 c.c. of dry soil into a second beaker and pour on to it 100 c.c. of boiling water, on stirring the mixture with a thermometer we shall find that the boiling water has warmed the dry soil to over 80° C. Since the same quantity of heat was used in each case, namely, the amount of heat contained in 100 c.c. of boiling water, it is evident that a given quantity of heat warms a given volume of dry soil to a much higher degree than it warms the same volume of water. In physical language we say that the specific heat of water is higher than that of soil. It is clear, therefore, that a wet soil will require more heat to warm it in the spring than a dry soil.

Wet Soils Cold.

A wet soil is, therefore, cold in the spring, both because the high specific heat of the water it contains will make it warm slowly, and because the evaporation of water from the surface will cool it by the absorption of latent heat of evaporation. And in a soil which is cold in the spring both crops, and the microbes which prepare nitrates for crops, will be late in starting to grow. Consequently a wet soil will be a cold soil and a late soil. This state of things can only be remedied by drainage and surface cultivation.

Colour and Slope.

The rate at which a soil gets warmed to a suitable temperature for plant growth in the spring is also affected by its colour and slope. When the sun's rays fall upon a surface some of them are reflected and some absorbed. Only those which are absorbed serve to warm the surface. The proportion absorbed depends on the nature of the surface. A bright smooth polished surface reflects nearly all the rays which fall upon it and consequently gets warm very slowly. A dull black surface absorbs nearly all the rays which fall upon it and gets warm very quickly. Dark coloured surfaces absorb well, light coloured surfaces absorb badly. Consequently, other things being equal a dark coloured soil will get warm in the spring more quickly than a light coloured soil.

The proportion of rays absorbed also depends on the angle at which the rays strike the surface, being greater as that angle approaches a right angle. Consequently a soil which slopes to the south will get warmed more quickly in the spring than a soil which slopes to the north.

Effects of Frost.

One more effect of climate will finish the chapter, and that is the effect of frost. When water is frozen to ice its volume increases considerably, and this increase in volume is capable of exerting very great force, so much so that pipes are burst when water freezes inside them. This increase in volume plays an important part in disintegrating the soil. When a heavy clay soil is ploughed up rough in the autumn, the clods on the surface absorb the winter rains so that their pores are filled with water. When this water freezes to ice inside the pores, the solid clods are torn apart by the expansion. When the ice thaws, the clods easily fall to pieces. After such treatment a clay soil works readily in the spring as soon as it is dry enough.

CHAPTER V.

VARIOUS SOIL CONSTITUENTS.

In Chapter II. we studied the methods of sampling soil and separating it into fractions consisting of particles of various sizes. We must now proceed to study the properties of these several fractions, with a view to discovering their effect on productivity. It will be useful to repeat the form in which the results of a mechanical analysis of a soil are entered :—

	Per Cent.
Stones	
Fine Gravel	
Coarse Sand	
Fine Sand	
Coarse Silt...	
Fine Silt	
Clay	
Organic Matter or Humus ...	
Water	
Loss, chiefly Calcium Carbonate	
Total	

Stones.

We need not waste time in discussing the part played by stones in the soil. It will suffice to remark that they provide no food for plants, but that by covering the surface they serve to hinder evaporation from the soil. This not only conserves water for the use of the crop, but checks the cooling effect of evaporation.

Fine Gravel.

Fine gravel also needs but little discussion. It is seldom present in any considerable quantity, and yields no plant food. If it affects productivity at all, it does so by tending to make the soil open and free working. From the investigator's point of view, these two fractions, stones and fine gravel, are worth attention. By examining them he may often find indications of the geological origin of the soil.

Coarse Sand.

Coarse sand is usually one of the most abundant constituents of a soil. It consists for the most part of grains of crystallized quartz, or silica, and, as such, contains no plant food. But sand, as separated from a soil, is by no means pure quartz. Among its grains are found many fragments of the minerals which composed the rock from which the soil was derived. The identification of these fragments may often give a clue to the origin of the soil. The properties of sand have already been discussed in Chapter III., when it was shown that sand was porous, not very retentive, rather dense, but possessed of small cohesion. It was shown that a mass of sand particles possessed considerable capillarity, and would raise water very rapidly to a considerable height.

Value of Sand.

Sand is, therefore, a valuable soil constituent: it keeps the soil porous, so that it can absorb the rainfall: though it is not very retentive of water, it can raise water rapidly from the subsoil: though it is heavy from the point of view of density its particles are large and without cohesion, so it keeps the soil open and easy to cultivate.

Fine Sand.

Fine sand differs only in degree from coarse sand. The comparative smallness of its particles makes it less porous and more retentive, and gives it rather greater power of raising water. As a rule it contains a smaller proportion of quartz and a larger proportion of particles of rock-forming minerals than does coarse sand.

Silt.

Silt, and especially fine silt, is a much less desirable constituent than sand. Fine silt particles are small enough if they are abundant in a soil to make the soil rather impervious, so that it does not absorb rainfall readily. Such soils also are apt to be cohesive and sticky when wet, and to dry into a hard cake on the surface. Soils in which fine silt predominates are, therefore, very troublesome to cultivate. Nor can they be improved by liming, as is the case with clay soils, as will be seen later. Silt particles are in part finely divided quartz, but among them are many fine particles of undecomposed minerals which supply potash and phosphate for plant food.

Clay.

Composition.

Clay, which consists of the finest particles in the soil, is entirely different in many respects from all the other fractions. Its particles are smaller in size, and possess a characteristic chemical composition. Clay particles are formed from the minerals contained in the parent rock, not merely by mechanical reduction in size, but by chemical change, which results in the decomposition of the minerals and the recombination of some of their constituents with water. Clay is, in fact, hydrated aluminium silicate, $H_2O . Al_2O_3 . 2SiO_2$. This is the formula of kaolinite, or pure china clay. In the clay, separated from a soil, some of the water is replaced by oxides of potassium, sodium, calcium, and magnesium, and iron oxide is also present. The formula may, therefore, be written—

$$\left.\begin{matrix} H_2O \\ K_2O \\ Na_2O \\ CaO \\ MgO \end{matrix}\right\} \left.\begin{matrix} Al_2O_3 \\ Fe_2O_3 \end{matrix}\right\} 2SiO_2.$$

Compounds similar to this in composition are found in the minerals known as zeolites. These zeolites occur naturally in crystalline form. Their examination has thrown much light on the properties of clay and its behaviour in the soil, and it seems probable that clay is similar to the zeolites in composition and in many of its properties. Since it contains potash, magnesia, and lime, clay is valuable in the soil as a source of plant food, but its physical properties are so overpowering that we must give to them our first attention.

Physical Properties.

Let us first repeat with dry powdered clay the experiments we made with sand, which are described on p. 30. The first thing we shall notice is that, when we pour water on to clay, the water penetrates the clay very slowly. Clay is non-porous, or, as we say, impervious. This property may, however, be modified to a considerable extent. For instance, if we acidify the water before we pour it on to the clay it will penetrate the clay much more quickly. If, on the other hand, we make the water slightly alkaline, by adding to it a few drops of sodium hydroxide solution, it will not enter the clay at all.

Puddled Clay.

The same condition of absolute imperviousness may also be attained by puddling the clay, that is to say, working it when wet into a plastic mass. Puddled clay is commonly used to line ponds in a porous soil so that they may hold water.

Density of Clay.

Let us now weigh out 100 grams of dry powdered clay, and measure its volume. We shall find that it fills about 100 c.c., so that its apparent density is 1 gram per c.c. The apparent density of sand was 1·5 gram per c.c. In point of density sand is, therefore, much heavier than clay, and a sandy soil is consequently heavier than a clay soil. When the farmer describes a clay soil as heavy and a sandy soil as light, he refers to the power required to drag cultural implements through them, and not to their densities.

Air Spaces in Clay.

We will now pour our 100 grams of dry powdered clay into a cylinder containing 100 c.c. of water so that the clay particles will fall through the water, leaving the air which occupied the spaces between the particles. This experiment requires much skill and patience. If we succeed we shall find that the clay particles will raise the level of the water to 140 c.c. or thereabouts. The volume of the clay particles is, therefore, 140 — 100 c.c., and their true density $\frac{100}{40}$, or 2·5 grams per c.c. In the original dry clay the volume of the particles was, therefore, 40 c.c. The total volume of the clay was 100 c.c., so that the air spaces must have occupied 100 — 40 = 60 c.c., or 60 per cent.

Reason why Clay is Impervious.

The air spaces in powdered dry clay occupy a much larger proportion of the total volume than do the air spaces in sand, and it is not because there are no air spaces that water cannot penetrate into clay. The reason is to be found in the very small size of the individual particles. Coarse sand particles vary in diameter from 1 mm. to ·2 mm. Clay particles are all smaller than ·002 mm. in diameter. The smallest coarse sand particles are, therefore, 1,000 times larger in diameter than the largest clay particles. The spaces between individual particles of clay will, therefore, be at least 1,000 times smaller than the corresponding spaces in sand. The spaces between clay particles are, in fact, so very small that water can hardly get into them because of the friction developed between the water and the surface of the particles.

Friction is proportional to surface, and King has found that in a given volume of a clay soil, the area of the surface of the particles is about 16 times as great as the area of the surface of the particles in the same volume of a sandy soil. It is obvious, therefore, that the friction developed when water tries to find its way between the particles of a clay soil is very great—it is, in fact, so great as to make the movement of water in clay extremely slow. Thus, although the smallness of the spaces between the particles of clay should give it the power of raising water to a great height by capillarity, the rate of rise may be made so slow by friction that surface rooting plants in clay soils may suffer before water can reach them.

Clay expands when wet.

Let us return once more to the experiment, and note the level of the top of the clay particles, which have settled through the water in the measuring cylinder. The top may be rather indefinite, but it will be easy to see that the clay which filled 100 c.c. when dry fills a greater volume when wet.

This increase may be due either to the particles themselves swelling when they soak up water, or to the water pushing them apart. Which of these causes is the true reason we do not know, but we do know that clay expands when it is wet, for it also contracts when dried.

Clay contracts in drying.

If we take a mass of wet clay and roll it out into a long column rather more than a metre long, we can easily measure the contraction. To do so we make two scratches, exactly a metre apart, on the column of clay, which is laid out on a board.

We measure the distance between these scratches from day to day as the clay dries, when we shall find that by the time it is dry and hard it will have contracted by more than 5 cm., *i.e.* by more than 5 per cent. of its length. It is this contraction of clay in drying that causes the formation of cracks in clay soils in dry weather.

Clay Foundations.

The expansion of clay when it gets wet, and its contraction on drying, takes place in all directions, not only horizontally but vertically, and is capable of exerting enormous force. It is a phenomenon which causes trouble in buildings whose foundations are laid partly over clay and partly over some other subsoil. The clay expands and contracts according to the amount of rainfall, whilst the other subsoil does not, so that the part of the building over the clay will be alternately raised and lowered. Sometimes this causes serious cracks in the structure.

Clay as a Colloid.

We have noticed when experimenting with clay, and especially when trying to make water percolate into it, that the presence of acid or alkali considerably affects its properties. We shall find it worth while to pursue this subject.

Grind up a little clay with distilled water, and shake the cream so produced with a large quantity of distilled water. Allow the mixture to stand for a few minutes so that the grit may settle, and pour the slightly turbid liquid into a series of gas cylinders, so that each cylinder contains about 100 c.c. To one cylinder add 2 c.c. N/10 HCl, to the second 1 c.c. N/10 HCl, to the third 1 c.c. N/10 NaCl, to the fourth 2 c.c. N/10 $CaCl_2$, to the fifth nothing. Stir the liquid in the cylinders, and then leave them to stand. In

Coagulation.

a short time the clay in the cylinder to which 2 c.c. N/10 HCl was added will begin to settle, and very soon the liquid in this cylinder will be clear with all the clay at the bottom. Soon the clay in the other cylinders to which acid or salts were added will begin to settle, and before long they, too, will become clear with all their clay at the bottom.

In order to find out what takes place we may put a drop of the turbid liquid on a microscope slide and examine it with a very high power. We shall see the clay particles as minute specks in rapid quivering motion. If we now put a drop of hydrochloric acid on the slide so that it touches the clay liquid, we shall see that, as the acid comes in contact with the clay particles, they run together into composite larger particles or "crumbs," and cease moving.

Clay particles exist in two states: as separate particles, which are so small that they float indefinitely in pure water; as larger compound particles, or crumbs, which sink through water in a comparatively short time. The change from the first state to the second is called coagulation, or flocculation. It can be brought about by acids or salts. Acids are most active in coagulating clay. Salts of divalent metals, such as calcium, are almost as active as acids. Salts of monovalent metals, like sodium or potassium, are much less active.

This coagulation of clay by salts is responsible for many important natural phenomena. The proverbial clearness of trout streams in chalk or limestone districts is due to the presence of calcium bicarbonate in the water, which flocculates the clay and causes it to settle out quickly and leave the stream clear.

The coagulating power of the salts in sea-water hastens the settling of the clay brought down to the sea by muddy rivers, and is a powerful factor in the formation of alluvium in the estuaries of rivers of this kind.

Effect of Nitrate of Soda on Clay Soils.

The fact that alkalis keep the clay particles in the separate floating condition explains the harmful effect of nitrate of soda on clay soils. Plants have more need of the nitrate than of the sodium, and when they absorb the nitrate the soil becomes alkaline. This prevents the clay from flocculating, and clay which is not flocculated is very difficult to cultivate when wet and dries into a hard cake. This harmful effect of nitrate of soda can be prevented by using with it sulphate of ammonia, which tends to make the soil acid.

Cultivation of Clay Soils.

When coagulated or flocculated clay is more porous, its particles do not stick together so closely, and it therefore works more easily, and it does not cake on drying. The art of managing a clay soil is, therefore, to keep the clay flocculated, and the most potent factor for achieving this end is a good supply of calcium carbonate in the soil. A soil which works badly should be sampled and analysed. If it is found to be deficient in calcium carbonate it should be limed, chalked, or marled. The fact that lime is alkaline sometimes causes confusion, because alkalis prevent flocculation. Lime, however, when applied to the soil, very quickly absorbs carbon dioxide and becomes calcium carbonate. This is converted by the carbon dioxide in the soil-water into a soluble salt, calcium bicarbonate, which actively flocculates the clay particles.

The flocculation of clay can also be destroyed by working it when it is wet. Such treatment breaks up the compound particles, and reduces the clay to a plastic condition, in which it dries to hard clods which may not break up until freezing in winter tears them apart by the expansion of the water when it freezes in their pores.

Clay a Colloid.

If we try to define the properties of clay we shall find it impossible to do so, except in relation to its surroundings. Clay in the presence of alkali is an excessively fine powder, the particles of which float indefinitely in water. When mixed with only enough water to wet it, a plastic mass is formed which can be moulded into any desired shape, which is retained on drying. Clay in contact with acids or salts consists of much larger compound particles, which settle rapidly out of water. It does not readily become plastic.

This characteristic of possessing properties which vary with the surroundings is shown by a large number of substances. White of egg, or albumen, for instance, as it exists in the egg is a thick glairy liquid. When heated it becomes a white insoluble solid. It is also coagulated by acids, but not by alkalis. Such substances are called colloids, from their resemblance to gelatine or glue, which in French is called *colle*. Clay is a colloid, and, as we have seen, its properties are modified by its surroundings. In managing a clay soil, what we have to do is to take advantage of this, and modify the properties of the clay as we have seen above. Soils in which fine silt predominates are as heavy to work as clay soils, and, as the silt is not colloid in nature, its properties cannot be modified by liming or other treatment. Such soils are, therefore, more difficult than clays because we have no way of improving them.

Humus.

The soil fraction known as organic matter, or humus, differs altogether from sand, silt, and clay, because, whilst they are composed of inorganic or mineral materials, humus consists chiefly of carbon, hydrogen, and oxygen, with a little nitrogen, and

Origin.

contains very little mineral matter or ash. It differs also in origin, for it arises from the partial decomposition of vegetable and animal matter, the remains of former crops or manurings, and not from the decomposition of rock or rock fragments. The changes which result in the formation of humus will be studied when we deal with farmyard manure. Here we will accept it as a soil constituent and study only its properties.

Leaf Mould.

It is difficult, in fact almost impossible, to separate humus from the soil, so we must be satisfied with using for our experiments the crumbly material obtained by rubbing well rotted leaf mould through a fine riddle, and drying it.

Density.

If 100 c.c. of such material is weighed, its weight will be found to be about 35 grams, and its apparent density is, therefore, about ·35 gram per c.c. It is impossible to find the real density by the method used for sand, but by other methods the real density is found to be about 1·2 grams per c.c.; 35 grams, therefore, occupy only about 30 c.c. Consequently 100 c.c. must contain 70 c.c. of air spaces.

Porosity and Retentiveness.

If 100 c.c. of dried leaf mould is placed in a funnel and 200 c.c. of water poured on to it, the water runs readily into the leaf mould. If a cylinder is placed below the funnel to catch the drainage, it will be found that considerably less than 100 c.c. will run through. The leaf mould must, therefore, have retained more than its own volume of water. This is possible because it swells up when wetted. Leaf mould, therefore, combines in a high degree the two valuable properties of porosity and retentiveness, and is a most desirable soil constituent, for it admits the rain and holds it as well. It is porous because its particles are fairly large, and, consequently, have large spaces between them. It is retentive because its particles still retain traces of their vegetable origin in the form of the tubes and vessels which existed in the plants from which they were formed. Each particle is, in fact, not a solid particle, but a sort of sponge. The water readily finds its way between the particles, and is then drawn into the very small spaces inside the particles by capillarity.

The particles of humus do not stick together like clay particles, but they are more coherent than sand particles. Consequently humus decreases the cohesiveness of clay, and makes it easier to work, but increases the cohesiveness of sandy soils, improving the texture in either case.

Composition.

Besides carbon, hydrogen and oxygen, humus contains nitrogen phosphate and potash, but in an insoluble condition, and, therefore, out of the reach of plants. But, being an organic substance, it is not exempt from decay, and, as decay proceeds the nitrogen phosphate and potash become soluble and available to crops.

Humus, therefore, acts as a store of plant food in the soil. It may be regarded as part of the capital of the soil, which, by continual decomposition, yields interest in the form of nitrates and other soluble plant food salts. From this point of view it would be vanishing capital were it not continually replaced by the remains of crops, by application of farmyard or other organic manures, or by green manuring. The maintenance of a proper stock of humus in the soil by these methods is most important, and is known as keeping the soil in good heart, or good condition.

Decomposition in the Soil.

The rate of decomposition of humus depends on two main factors, aeration of the soil, and the presence of calcium carbonate. Aeration depends on drainage and cultivation. In well-drained and cultivated arable soil, aeration is good and humus decomposes rapidly. Consequently the proportion of humus is seldom high in such soils.

Humus in Grass Land.

In grass land there is, of course, no cultivation, and humus consequently tends to accumulate. This accumulation of humus in grass land is increased when the soil is deficient in calcium carbonate. Under these conditions the surface of the soil may be covered with humus in the form of a mat of partially decayed grass roots several inches thick. Such a state of things may provide a soft surface for horses to gallop on, but is not conducive to the production of good herbage for either grazing or hay. Very thorough harrowing in winter, followed by a dressing of lime or basic slag, or both, will rapidly cause the oxidation of the surface humus, and improve the herbage.

Humus in Prairie Land.

Enormous accumulations of humus also occur in prairie land under certain conditions. When such land is broken up, the humus decomposes very rapidly when the soil is aerated by cultivation, and in decomposing yields much available plant food. This is the reason why broken up virgin soils will grow corn crops for many years without manuring. For the same reason old grass land when broken up will yield heavy crops for some time if wire worm and other pests can be circumvented. To a less degree also, land which has been under grass for even two or three years is found to have accumulated much fertility, and this method of maintaining fertility has taken a permanent place in the practice of many districts.

Neutral Humus.

When vegetable matter has decomposed in contact with an abundant supply of calcium carbonate, the acids formed in the process, known collectively as humic acids, are found to have combined with the calcium carbonate. The resulting humus consists largely of calcium humates. This is the state of things in most soils, and in the peat of the Cambridgeshire fens. Humus of this kind is neutral, and immediately fertile. To prepare humic acid from it, the best method is first to decompose the calcium humates with hydrochloric acid. After the $CaCl_2$ and the excess of HCl have been removed by washing, the humic acids dissolve easily in ammonia, forming a dark brown solution. On acidifying this solution, the humic acids are precipitated as brown flocks.

Sour Humus.

In many cases, however, humus has been formed by the decay of vegetable matter in the absence of calcium carbonate. Under these conditions, the humus is acid or sour from the presence of much free humic acids. This is the case in moorland soils deficient in calcium carbonate, and in peats formed in districts where the water and the soil contain no calcium carbonate. Such humus is sterile for ordinary crops, and can only be made fertile by continued applications of lime or calcium carbonate, combined with good cultivation to promote aeration.

CHAPTER VI.

CHEMICAL EXAMINATION OF CROPS AND SOIL.

Chemical Factors of Productivity.

In our discussion of the factors which govern the productivity of the soil we found that in addition to supplying the crop with water, oxygen, and warmth, the soil must also provide the plant with food in the shape of compounds of nitrogen, phosphoric acid, potash and lime, together with a number of other compounds which are of little practical importance. We must now turn our attention to the study of these important factors of productivity, nitrogen, phosphoric acid, potash and lime, in order that we may find out how much of each of them our crops require, and how they get it from the soil; how much the soil contains, and how we can recognise and make good deficiencies.

Manuring only one Factor.

The accurate study of this branch of the subject began over one hundred years ago, and from that date up to about thirty years ago it formed the most important, indeed almost the only, branch of agricultural chemistry. We still recognise the importance of the supply of plant food to our crops as shown by the fact that we use annually in Great Britain nearly two million tons of artificial manures, but we recognise nowadays that manuring even when based on analyses of the soil is not a panacea for all the difficulties we encounter in crop production.

We recognise also that chemical methods will not enable us to find out all we ought to know about the way the soil supplies food to our crops, and in this and the following chapters we shall have to utilise facts discovered by agriculturists, botanists and bacteriologists in order to arrive at a satisfactory answer to the problem before us.

Nitrogen, Phosphoric Acid, and Potash.

For the present we will limit our enquiries to nitrogen, phosphoric acid, and potash. Lime comes in rather a different category. Practically all soils can supply crops with all the lime they require, but many soils require lime or chalk to maintain them in a good state of texture and cultivation and to prevent them from becoming sour. Lime is, therefore, used rather to improve the soil than to feed the crops. This is officially recognised in the Feeding Stuffs and Fertilisers Act which only includes nitrogen, phosphoric acid, and potash among the fertilising ingredients of manures.

Manurial Requirements of Crops.

The first problem then is, how much nitrogen, phosphoric acid, and potash do our crops require? This question is readily answered if we know the weight of each crop per acre, and the percentage of nitrogen, phosphoric acid, and potash which it contains.

As to the weight per acre of each crop, we can easily find average figures from the statistics of the Ministry of Agriculture. But we will not be satisfied with average crops. We will base our calculations on good crops. In the case of wheat for instance, the average crop is about four quarters per acre, but we will assume that we ought to grow five quarters, and that this amount of grain corresponds to 1½ tons of straw.

The average of many analyses of wheat grain, and straw, show that the grain contains 1·8 per cent. of nitrogen, ·5 per cent. of potash, and ·8 per cent. of phosphoric acid, and the straw ·45 per cent. of nitrogen, ·62 per cent. of potash, and ·22 per cent. of phosphoric acid.

We can now calculate the amounts of nitrogen required by a good crop of wheat as follows :—

4 quarters of grain at 504 lb. per quarter = 2016 lb.
1½ tons of straw = 3360 lb.
2016 lb. grain containing 1·8 per cent. N. = 36 lb. N.
3360 lb. straw „ ·45 „ „ „ = 15 „ „
Total requirement for grain and straw = 51 lb. N.

2016 lb. grain containing ·8 per cent. phosphoric acid = 16 lb.
3360 lb. straw containing ·22 per cent. phosphoric acid = 7 lb.
Total requirements for grain and straw = 23 lb.

2016 lb. grain containing ·5 per cent. potash = 10 lb.
3360 lb. straw „ ·62 „ „ „ = 21 lb.
Total requirements for grain and straw = 31 lb.

A good crop of wheat therefore requires per acre about 50 lb. of nitrogen, 20 lb. of phosphoric acid, and 30 lb. of potash.

The following figures have been ascertained by similar methods :—

Crop.		Lb. per acre.	
	Nitrogen.	Phosphoric Acid.	Potash.
Wheat, 5 qr. and straw ...	51	23	31
Barley, 5 qr. and straw ...	50	21	35
Oats, 7½ qr. and straw	70	27	60
Meadow hay, 1½ tons	50	12	50
Clover hay, 2 tons	100	25	85
Beans, 4 qr. and straw	80	30	70
Swedes, 15 tons and leaves ...	100	22	80
Mangolds, 25 tons and leaves ...	150	50	300
Potatoes, 6 tons and haulm ...	70	25	80

These figures do not include the nitrogen, phosphoric acid, and potash contained in the roots of the cereals, grasses, and beans, and in the smaller roots of the swedes, mangolds, and potatoes. These roots remain in the ground, and when they decay their nitrogen, phosphoric acid, and potash become available to crops.

Requirements of Cereals small.

The figures show that the amounts of nitrogen, phosphoric acid, and potash required by crops are comparatively small, especially in the case of the cereals. This is worthy of note, as the cereals are commonly regarded as crops which exhaust the soil. It is stranger still that the root crops, which are usually considered to be restorative crops from the point of view of fertility, should require from the soil very much more plant food than the cereals. Evidently we must revise our ideas on the subject of exhausting and restorative crops, for cereals do not exhaust the soil of plant food, and root crops do.

Roots a Cleaning Crop.

The real difference between these crops is that cereals cover the ground all the summer and make it difficult to cultivate the soil and keep down weeds. Root crops are sown late, so that much cleaning can be done before they are sown. Inter-cultivation can then be continued almost all the summer, because they are sown in rows wide enough apart to admit of cultivation between them. By growing root crops the farmer is enabled to clean and cultivate his land. It is in this that the real restorative power of the root crop lies.

Nitrogen Supply of Leguminosæ.

The large amount of nitrogen required by the leguminous crops, clover and beans, should also be noted. Although these crops require so much nitrogen, they do not exhaust the soil of this constituent, because they have a special power of getting their nitrogen from the air through the agency of microbes which are found on their roots. This point will be dealt with more fully later. It is interesting here because it shows that the presence of a high proportion of nitrogen in a crop indicates rather that the crop possesses a special way of supplying itself with nitrogen than that it specially needs nitrogenous manure. Hence we cannot get reliable information about manuring a crop by the simple method of analysing the crop and compounding the manure according to its (the crop's) composition.

Amounts of Nitrogen, Phosphoric Acid, and Potash in Soils.

Nor does ordinary chemical analysis of the soil give direct indications as to manuring, as is shown by the following considerations. If we analyse an ordinary arable soil we shall find that it contains, as a rule, between ·1 and ·15 per cent. of nitrogen, between ·15 and ·2 per cent. of phosphoric acid, and between ·3 and ·8 per cent. of potash.

We can readily work out these figures per acre, for we have already found that an acre of soil nine inches deep weighs about 2½ million pounds. On this basis an ordinary soil contains the following amounts per acre in the first nine inches:—Nitrogen, 2,500 lb. to 3,750 lb.; phosphoric acid, 3,750 lb. to 5,000 lb.; potash, 7,500 lb. to 20,000 lb. The roots of crops penetrate the soil to a much greater depth than 9 inches, in many cases to a depth of 3, 4, or even 5 or 6 feet, so that, although the deeper layers of the soil may not be as rich in plant foods as the top nine inches, we are safe in estimating that the amounts of nitrogen, phosphoric acid, and potash within reach of the roots of crops are, at least, four times the amounts contained in the top nine inches, *i.e.* of nitrogen about 10,000 lb., of phosphoric acid at least 15,000 lb., of potash at least 30,000 lb.

Comparing these figures with the amounts required by crops, it is evident that ordinary soils contain enough plant foods to provide for, at least, 100 years' continuous cropping. Evidently ordinary analysis of soils is not likely to give us very direct indications about manuring.

Need of Manuring

How, then, are we to attack the problem? First, let us see if manuring is necessary. During the last thirty years hundreds of manuring experiments have been made in all districts of the country. These experiments have shown conclusively that, even on soils, which are found by analysis to contain the enormous stores of nitrogen, phosphoric acid, and potash quoted above, the application of, say, 20 or 25 lb. of nitrogen in the form of nitrate of soda usually increases the wheat, barley, or oat yield by as much as one quarter per acre. Now, even at present prices, 1 cwt. of sulphate of ammonia can be applied at a cost not exceeding 25s., and 1 quarter of wheat sells for 95s., so that manuring of this kind is both necessary and [illegible]

Again, it has been found tha[illegible] 50 lb. of phosphoric acid, in the form of 4 cwt. of superphosphate, often increases the swede crop by as much as three or four tons per acre. The cost of 4 cwt. of superphosphate is at most 30s., and swedes are worth about 20s. per ton. Here, again, such manuring is profitable.

Large increases are not so commonly produced by the application of potash, but the writer has experimented in one district, where the use of 1 cwt. of muriate of potash increased the yield of barley from 10 bushels per acre to 45 bushels per acre, and this result was obtained on a soil in which chemical analysis indicated quite a normal store of potash. We may conclude, therefore, from the results of field experiments that judicious manuring is generally both necessary and profitable. How, then, are we to find out how to manure judiciously if ordinary analysis of crops and soil will not help us?

CHAPTER VII.

TESTING THE SOIL. NITROGEN.

After our discussion in the last chapter, from which we concluded that manuring was both necessary and profitable if it could be done judiciously, it will perhaps clear the air if we return to our factors of productivity, so that we may be quite certain where we are.

Limits of Manuring.

Of the many factors, only a few can be dealt with by manuring. We can, by manuring, enable the soil to supply the commonly deficient plant foods, nitrogen, phosphoric acid and potash. We can by liming, chalking, or marling remedy the troubles which occur when the soil is deficient in chalk. To a certain extent we can improve soils deficient in humus by large dressings of farmyard manure, or by green manuring. All these things can be done provided we can find some method of recognising the deficiencies which is more searching than ordinary chemical analysis.

Field Experiments.

The best method, if time and trouble are no object, is that to which we referred in the last chapter, the method of field experiment. This method in its simplest form is usually carried out by what is known as the 8-plot test. It is carried out as follows: 8 equal plots, usually ¼ acre each, are marked out on a uniform field of land which is typical of the district. These plots are manured as follows:—

Plot 1. Complete manure supplying nitrogen, phosphoric acid and potash.
Plot 2. Nitrogen and phosphoric acid only.
Plot 3. Nitrogen and potash only.
Plot 4. Potash and phosphoric acid only.
Plot 5. Nitrogen only.
Plot 6. Phosphoric acid only.
Plot 7. Potash only.
Plot 8. Unmanured.

All the plots are similarly cultivated, and sown with the same sample of seed on the same day, so that their treatment differs only in manuring. The produce of the plots is harvested and weighed separately, and the results entered as in the annexed table which refers to an experiment with barley.

	Manuring.	*Yield, Bushels of Barley.*
Plot 1.	Complete manure	52
Plot 2.	Nitrogen and phosphoric acid ...	51
Plot 3.	Nitrogen and potash	50
Plot 4.	Phosphoric acid and potash ...	32
Plot 5.	Nitrogen only	50
Plot 6.	Phosphoric acid only	31
Plot 7.	Potash only...	30
Plot 8.	Unmanured	30

Interpretation of Results.

These results are interpreted in the following manner. The effect of nitrogenous manuring is shown by the difference between plots 5 and 8, and between plots 1 and 4, which is 20 bushels in each case. We infer therefore that the soil is deficient in nitrogen for the barley crop. Similarly the effect of phosphoric acid is shown by comparing plots 1 and 3, and plots 6 and 8. These differ by 2 and 1 bushels respectively, and we therefore conclude that the soil is not appreciably deficient in phosphoric acid for the barley crop.

The use of potash only on plot 7 produced no increase above the unmanured plot, and the potash applied in the complete manure to plot 1 only increased the yield above plot 2 by 1 bushel. Evidently the soil is not deficient in potash for the barley crop. Our final conclusion from the whole experiment is that, from the point of view of the barley crop, the soil is deficient in nitrogen but not deficient in either phosphoric acid or potash.

Defects of Method.

The defects of this method are (i) that it occupies a whole season, (ii) that it involves much trouble, (iii) that it gives different results with different crops, and (iv) that on account of the lack of uniformity in the soil, in the attack of insect and fungoid pests, and in other conditions, the results are not reliable unless the experiment is repeated many times. In view of these defects in the field experiment method of testing soils, we still require a method of testing a soil in the laboratory which will tell us if it is deficient in nitrogen, phosphoric acid, or potash, and if it lacks calcium carbonate or humus.

Nitrogen.

We must, therefore, try to discover such a method, and we will begin with nitrogen. Let us first enquire why an ordinary chemical analysis fails to tell us when a soil is deficient in the power of supplying nitrogen to crops. Botanists have found out that a plant absorbs its food from the soil through its root-hairs, which are situated only on the smallest and thinnest rootlets. These root-hairs have cell walls, and the food is absorbed through the cell walls by the process known as osmosis, and must therefore be in solution in the soil water before it can be absorbed.

Humus Insoluble.

Now almost the whole of the store of nitrogen in th soil exists in the form of humus. Humus i not soluble in water, and its nitrogen i therefore not available for feeding crops This explains at once why a soil containing 10,000 lb. pe acre of nitrogen, within reach of the roots of a crop may be unable to provide that crop with as little a 50 lb. of nitrogen. It also explains why the total amoun of nitrogen in a soil as found by analysis does no give reliable information as to whether the soil require nitrogenous manure. The difficulty is that a soil ma contain abundance of nitrogen which is not available t crops.

Available Nitrogen.

For practical purposes what we want is a method fo finding out if the soil contains availabl nitrogen. Let us turn once more to th plant. Botanists have found that plan absorb their nitrogen from the soil in the form of nitrat usually calcium nitrate. Available nitrogen is, therefor nitrogen in the form of nitrate, and we shall get the information we are looking for if we can find if the so contains nitrate.

Testing for Nitrate.

Fortunately, this can be done quite easily because a nitrates are very soluble in water. Tak 10 grams of the soil, which must be a freshl taken sample, shake it up with 50 c.c. distilled water, and filter. Since nitrates are very solubl they will be found in the filtrate. To 1 c.c. of the filtra add 3 c.c. of pure strong sulphuric acid, shake unt thoroughly mixed, and cool under the tap. Now add 1 c. of a specially prepared solution of carbazol, and shal again. If there was any nitrate in the soil, a green colo will be formed, and the depth of the colour will be pr portional to the amount of nitrate.

Estimating Nitrate.

The actual amount can be roughly estimated thus. A standard solution of potassium nitrate is prepared of such strength that 1 c.c. contains ·00001 gram of nitrogen. Five clean test-tubes are now taken and into the first is measured ·1 c.c. of this solution, into the second ·2 c.c. and so on up to ·5 c.c. in the fifth. Distilled water is now added to each tube to make up the volume of the solution to 1 c.c. The tubes will now contain in order ·000001 gram N. as nitrate to ·000005 gram, in each case dissolved in 1 c.c. To each tube 3 c.c. of pure strong H_2SO_4 is now added, and the tube shaken and cooled. When cool, 1 c.c. of carbazol solution is added, the tubes are shaken and placed in order in the stand for the green colour to develop. The tube containing the soil-water and carbazol is now placed beside the standard tubes for comparison of the colours. Suppose its colour is midway between that of the two tubes containing ·000002 gram N. and ·000003 gram N. Then we may conclude that the 1 c.c. of soil-water contained about ·0000025 gram N. as nitrate. But 50 c.c. water was added to 10 grams soil, so that 1 c.c. of soil water contains the nitrate from 10 ÷ 50 = ·2 gram soil. Therefore, ·2 gram soil contains ·0000025 gram N. as nitrate. The percentage of N. as nitrate in the soil is therefore

$$\frac{\cdot 0000025 \times 100}{\cdot 2} = \cdot 00125 \text{ per cent.}$$

The percentage of total nitrogen in an arable soil is usually between ·1 and ·15, so that only about one hundredth part of the total nitrogen exists as nitrate.

We found in Chapter II. that an ordinary soil nine inches deep weighs about $2\frac{1}{2}$ million pounds per acre. The weight of nitrate per acre is therefore

$$\frac{2500000 \times \cdot 00125}{100} = 31 \text{ lb.}$$

This is about the usual amount of nitrogen as nitrate an ordinary soil, and we can now understand why t addition of 25 lb. of nitrogen as nitrate of soda shou make a large increase in the crop, for the crop can o feed on the nitrate, and 25 lb. of extra nitrate alm doubles its nitrogenous food supply.

This method of estimating the nitrate in a soil, therefo gives us very valuable information about the need nitrogenous manure. But it is a method which requi great care, for it is so delicate that we are very liable find nitrate by accident. The tubes must be cleaned v carefully, and the distilled water and the sulphuric a must be quite free from nitrate. It is always advisa to make a blank experiment by mixing 1 c.c. of distil water, 3 c.c. of sulphuric acid, and 1 c.c. of carbazol soluti If the tube is clean and the water and acid are pure green colour should be produced.

The result of this test raises several interesting a important questions. If the soil contains only ab 30 lb. of nitrogen as nitrate per acre and a crop u 50 lb., why does not one crop exhaust the soil?

Rothamsted Drain Gauge.

The answer to this question is given by an experime carried out at Rothamsted. More th 40 years ago a block of soil exactly $\frac{1}{1000}$ of acre in area, and 20 inches deep, was isolat in its natural condition by undermining it so that a sh of perforated iron could be pushed under it. The soil w then dug out all round and cement walls built round block from the perforated bottom upwards. A very la funnel was placed underneath the block of soil, so th the water draining through it could be collected. T surface of the soil was kept loose and free fr weeds. An arrangement of this kind is called a dra gauge.

Every month the water which has drained through the soil is collected, and analysed by a method similar to the one we have used for estimating nitrate. This was done for 26 years, from 1878 to 1903 inclusive with the following average results:—

	Nitrogen as Nitrate in drainage. Lb. per acre.
January	3·8
February	3·4
March	1·5
April	·9
May	1·1
June	1·4
July	1·9
August	2·5
September	3·2
October	5·8
November	6·2
December	4·6
Total per year	36·3

Formation of Nitrate in Soil.

Rain falls on the surface of the soil, some of it evaporates, but about half percolates through. Since nitrate is so soluble, this drainage carries with it any nitrate contained in the soil. In this way just over 36 lb. of nitrate per acre have been washed out of the soil every year for 26 years, or in all 944 lb. Now all this nitrate could not have been in the soil to start with, for being so soluble it would have been washed out the first year. It must therefore have been formed in the soil or brought down to the soil in the rain. The nitrogen in the rain has been estimated continuously at Rothamsted since 1886, and found to amount to about 5 lb. per acre per annum. If we subtract this, there still remains 31·3 lb. of nitrogen as nitrate per acre per annum which must have been forme in the soil.

Nitrate formed from Humus.

Now the only soil constituent which contains nitroge is humus, and since during the 26 years th humus in the block of soil has decreased, w can safely conclude that the nitrate washe out of the soil must have come from the decomposition o the humus.

Source of Nitrate.

It has been known for a long time that nitrate is forme from the decomposition of animal and vegetable materials. Indeed, until the discover of nitrate of soda in Chili 60 years ago, th world's main sources of nitrates were the domesti rubbish heaps of the Silesian peasants and the drains i India. In both cases animal and vegetable refuse wa allowed to decompose in the presence of wood ashes t supply potash, and potassium nitrate was obtained b dissolving it from the surrounding soil by hot water, fron which it was subsequently crystallised.

Nitrate Formation caused by Microbes.

The exact cause of the decomposition was not worke out until 1890, when Warington at Rothamsted and Winogradski at Paris simultaneously succeeded in isolating th microbes and discovering their condition of growth.

Ammonification.

We now know that the decomposition proceeds in thi manner. In the first place various microbe and microscopic fungi, called ammonifyin organisms, which are found in the soil, i manure heaps, and in such places as stables and cowsheds feed upon the vegetable and animal matter in the soil and convert some of it into carbon dioxide, water an ammonia, leaving a residue which is humus. This chang is at first quite rapid, but when once the humus is formed though the same kind of change continues, it is very slow indeed as shown by the fact that in the Rothamsted drain-gauge much of the original humus still remains undecomposed and yields a little nitrate every year.

Nitrification.

As soon as ammonia is formed in the soil it becomes the food of another kind of microbe, called nitrosomonas, which converts it into calcium nitrite. This microbe can only grow in the presence of air, to supply the necessary oxygen to convert NH_3 into HNO_2, calcium carbonate, to neutralise the HNO_2 and convert it into calcium nitrite, $Ca(NO_2)_2$, and a suitable temperature. This change is quite rapid when conditions are suitable, more rapid in fact than the preceding change of humus into ammonia, so that practically no ammonia is found in a soil in good condition.

But calcium nitrite does not remain in the soil. It is at once attacked by still another kind of microbe, called nitrobacter, which feeds upon it and converts it into calcium nitrate, the salt which forms the nitrogenous food of our crops.

The first part of this process, namely, the change of vegetable and animal matter into CO_2, H_2O, NH_3, and humus is usually called ammonification. It is most rapid in stables, and in heaps of manure where the smell of ammonia is often noticeable. It will be discussed more fully in the chapter on farmyard manure.

The two last stages in the process, namely, the conversion of ammonia to nitrite and then to nitrate are known together as nitrification.

The whole process is most important, because it is responsible for the preparation of the nitrates on which our crops feed. If the conditions existing in a soil are unsuitable for the growth of the ammonifying and nitrifying microbes, these microbes will not be able to convert into the available form of nitrate a normal proportion the vast quantity of nitrogen stored in the soil in the for of humus, and this great capital stock of fertility w cease to yield fair interest.

It is most important, therefore, to test a soil so that may find out if it contains a fair proportion of nitrate. it does not at the moment contain any, the deficiency ma be due to the fact that the sample was taken after muc rain which may have washed out all the nitrate. Sampl for this test should not be taken after much rain or in th winter or spring when the nitrate is likely to have bee washed out.

We may, however, overcome this difficulty by keeping second portion of the sample of the soil warm and moi for about a fortnight when the test should be repeate If after this treatment a fair proportion of nitrate is foun then the soil is capable of preparing nitrate for our crop If, however, when the test is repeated no nitrate is foun we must conclude that there is something wrong with th soil conditions. It may be lack of aeration caused by ba cultivation or deficient drainage, or the soil may contai no calcium carbonate. These conditions must be furthe investigated and if possible ameliorated, when the fertilit of the soil will be improved. Cultivation and drainag has already been discussed. Calcium carbonate will b dealt with later.

Still another interesting point arises from the table o p. 91. It is notable that the amount of nitrate washe out of the Rothamsted drain-gauge varies greatly fro month to month. It is highest in late summer and autum and lowest in winter and early spring. This variation due to the fact that all the microbes concerned in nitrat production grow slowly when the soil is cold in winter an more rapidly as the soil gets warmed in spring and summe

Washing out of Nitrate.

Further, the nitrate produced in the spring and summer by the rapidly growing microbes is not washed out at once, because in the summer evaporation from the surface is rapid, and consequently not much water percolates through the soil. As the autumn progresses into winter, evaporation gets less and percolation increases, so that the nitrate which has accumulated in the soil during the summer is washed out.

Spring Crops require Nitrate.

Two very important practical lessons can be learned from this. Even in a fertile soil there will be little nitrate in the spring. Consequently crops like the cereals which should begin to grow early in the spring usually require an early application of nitrogenous manure, whilst turnips and swedes which are sown much later can often do without a direct application of nitrogen.

Secondly, any nitrate left in the soil after the crop has ceased growing in the autumn will be washed out in the winter, so that nitrogenous manures as a rule give their whole result the year they are applied and leave no residue for the next year. In this connection it should be pointed out that nitrogenous manures, except nitrates, are converted into nitrate in the soil before the crop uses them. This point will be discussed later.

Finally, by testing for nitrate in a soil, we learn if the soil is capable of supplying our crops with nitrogen. If it is, we may still find it necessary to use spring applications of nitrogenous manures for cereals, in order to supplement the normal supply of nitrogen by the soil. If it is not, we shall probably find on further investigation that the remedy is rather draining, improved cultivation or liming, than increased use of nitrogenous manures.

Protozoa. We have learned above that the preparation of nitra for crops to feed on is brought about by tl activities of certain kinds of microbes, ar we have found that if the growth of these microbes hindered by bad aeration or by deficiency of calciu carbonate, the productivity of the soil is decreased.

Russell and Hutchinson at Rothamsted have found tha in certain soils, especially those which are abnormally ric in humus, certain microscopic animals called protozoa a found in large numbers. These protozoa feed upon tl soil microbes and may diminish their numbers to such a extent as to check the formation of nitrate and decreas productivity. This state of things occurs most frequentl in the very rich soils prepared for growing tomatoes an cucumbers under glass, and in the soils of sewage farms.

Fortunately, these harmful protozoa are very easy t kill. By heating the soil, or by mixing with it a mil disinfectant which soon evaporates away, such for instanc as toluene, the protozoa are killed without permanen damage to the microbes. After this treatment, which i called partial sterilisation, the number of microbes in th soil increases enormously, more plant food is formed an the soil regains its productivity. The treatment also kill eel-worms and possibly other parasites which attack th crops. The same result can be obtained by the use of lim

CHAPTER VIII.

TESTING THE SOIL. PHOSPHORIC ACID AND POTASH. RETENTION OF MANURES IN THE SOIL.

Stores of Phosphoric Acid and Potash in the Soil.

In our discussion of the subject of soil analysis in Chapter V., it was pointed out that chemical analysis of soils by ordinary methods showed that ordinary soils contained, within the range of the roots of ordinary crops, from 4,000 to 5,000 lb. per acre of phosphoric acid, and from 7,000 to 20,000 lb. of potash, and that these amounts would suffice to grow ordinary crops continuously for from 100 to 200 years. Arguing from analogy with what we learned in the last chapter about nitrogen in the soil, we may consider that these large stores of phosphoric acid and potash represent, so to speak, the capital stocks of the soil, the interest of which provides the yearly supply of available phosphoric acid and potash for our crops. In the case of nitrogen we found that the capital stock existed in the soil in the form of humus, which, under the influence of microbes growing under certain conditions, yielded interest in the form of available nitrates.

Humus being formed by the decay of animal and vegetable matter contains a certain store of phosphoric acid and potash, some of which is, no doubt, made soluble and available when the humus is decomposed by the ammonifying microbes, but we know almost nothing on this sub-

ject. The great bulk of the store of phosphoric acid a
potash in the soil exists in the form of mineral particl
which are decomposed not by microbes, but by the acti
of water, carbon dioxide, frost, and other agencies of th
kind, which are usually classed together as weathering.

Phosphoric Acid and Potash in the Soil Water.

From the decomposition of the humus and the mine
particles, a certain amount of soluble pho
phoric acid and potash probably results, b
the amount which dissolves in the soil wat
is exceedingly small. The water which flo
from the drains of one of the experiment
fields at Rothamsted has been collected and analysed
several occasions. It contains on the average 13·2 parts p
million of nitrogen as nitrate, but only 1·1 parts per milli
of phosphoric acid, and 3·2 parts per million of potas
Evidently water can dissolve so little phosphoric acid a
potash from the soil that we cannot test the soil for availab
phosphoric acid and potash by shaking it with water.

Available Phosphoric Acid and Potash

Many chemists have given much time to the investig
tion of the phosphoric acid and potash in t
soil, in the hope of finding a satisfacto
method of estimating the proportion of the
substances available to crops. A perf
method is still lacking, but Dyer has d
covered a method which, if not altogether satisfactory, h
thrown much light on the subject. Dyer argued that
water could not dissolve enough phosphoric acid a
potash out of the soil to account for the amount contain
in crops, then the roots of the crops themselves mu
possess some power of dissolving these constituents fr
the soil particles. He grew all the ordinary crops und
such conditions that he could separate their roots in
clean condition, free from soil. He then separated t
cell-sap of the roots and analysed it. From the results

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his analyses he concluded that the cell-sap of the roots of ordinary crops was acid, that the acid present in the cell-sap was usually citric acid, and that the concentration of acid was on the average equal to that of a 1 per cent. solution of citric acid crystals. He then decided to try if a 1 per cent. solution of citric acid, which might be regarded as a close imitation of the cell-sap of the roots of ordinary crops, would dissolve from soils of known history amounts of phosphoric acid and potash in agreement with the known history of the soils.

He analysed by this method the soils of many of the Rothamsted plots whose history was known since 1845, and in every case the citric acid dissolved amounts of phosphoric acid and potash which were in agreement with the treatment which the plots had received. Other chemists have applied the method to other soils whose abundancies and deficiencies had been discovered by field experiments. In almost every case the citric acid method has given reliable indications of the abundance or deficiency of phosphoric acid and potash. The method has also been found useful in testing phosphoric acid manures to decide the extent to which the phosphoric acid they contain is available to crops. So far, then, it seems to be satisfactory. But, unfortunately, it involves so much skill in manipulation that it only gives reliable results in the hands of a practised analyst.

Dyer's Method.

It is carried out as follows:—A Winchester quart bottle is carefully cleaned. Into it is put 200 grams of the sample of soil to be tested, 2,000 c.c. of distilled water, and 20 grams of citric acid crystals. The bottle is stoppered and thoroughly shaken, the stopper being released several times to allow the CO_2 given off by the action of the acid on the calcium carbonate of the soil to escape. It is then set aside for eight days, being shaken three times every day. A eight days, the clear liquid is filtered from the soil, 500 c.c. measured out and evaporated to dryness. residue is then heated over a burner, to burn away citric acid and the organic matter dissolved from the s The phosphoric acid and potash are then estimated.

The method is too difficult for us to carry out oursel but, fortunately, the experience which has been accum lated from numbers of analyses which have been ma and from numbers of field experiments which have be carried out on typical soils in various districts, will se to tell us when to use phosphoric acid or potash manu without our having to analyse our own soils.

When to use Phosphatic Manures.

All soils, almost without exception, require manur with phosphoric acid at least once in ev rotation. After experimenting on soils ten counties for over 25 years, the wri has only found one isolated district wh phosphatic manures failed altogether to produce a defin increase. The crop which seems least able to extr phosphoric acid for itself from the soil is the turnip cr and we shall not go far wrong if we apply phosphoric ac to the turnips and swedes every time they come round the rotation. Phosphoric acid is not washed out of the so What is left by the root crop will suffice for the cereals other crops included in the rotation. Permanent gra too, very frequently requires and pays for phospha manuring. This subject will be dealt with again later.

When to use Potash Manures.

Potash is not so generally deficient in soils as phospho acid. Soils, as a rule, contain much m potash to start with. We have seen th the store of potash in a soil frequent amounts to as much as 20,000 lb. p acre. Our system of farming also tends to conserve t potash in the soil. Potash accumulates in the stems of plants and is, therefore, abundant in hay and straw. These products are consumed on the farm, and the potash they contain is returned to the soil in the form of farmyard manure. Phosphoric acid—and nitrogen too—accumulate in the seeds of plants, and in the bones and flesh of animals, and in milk. All these products are sold off the farm. This has been the custom for a very long time. Consequently our soils have been gradually exhausted of phosphoric acid and nitrogen, and the need for manures containing these substances is general. Potash has been conserved, and is therefore needed only on soils in which it is naturally deficient, that is to say on light sandy soils, and sometimes on peats. The crops which are least able to extract potash from the soil for themselves are potatoes, mangolds, turnips, and swedes. Except potatoes, these crops can usually get all the potash they require on loams or clay soils. On sandy soils their yield is definitely improved by potash manuring. Potatoes on all soils require potash manures, as do all market garden crops. Potash is not washed out of the soil. If we use potash when we grow these crops, enough will be left in the soil for the other crops included in the rotation.

This information will as a rule guide us quite well in the use of phosphatic and potash manures. In case of doubt we can always get a citric acid analysis of our soil made at the local college or by the county analyst. If we write to the county organiser or to the college we may find that in the course of its soil survey work, the college has experimented on the soil of our district either in the field or in the laboratory. The results obtained will probably give the information we want.

Phosphatic and Potash Manures not washed out of Soil.

In the course of our discussion of nitrogen, phospho
acid and potash in the soil we have fou
that nitrates are readily washed out of t
soil in the drainage, whilst drainage wat
contains very much less phosphoric acid a
potash, and we have concluded from t
that nitrogenous manures which are not absorbed by t
crop to which they are applied are washed out of the la
in the succeeding winter, whilst phosphatic and pota
manures are not washed out of the soil, but remain the
to the advantage of succeeding crops. This is an importa
conclusion which should be supported by further eviden

Retention of Manures by the Soil.

Make dilute solutions of a number of common manur
for instance, nitrate of soda, sulphate
ammonia, superphosphate, and muriate
potash, by weighing out 1 gram of eac
shaking up with 1000 c.c. of distilled wat
and filtering. Take 100 c.c. of the nitrate of soda soluti
in a flask. Add to it 50 grams of soil, shake well, leave
stand some time and filter. Now place in a test-tu
about 10 c.c. of the filtrate, and in a second test-tube
equal volume of the original nitrate solution. Add to ea
a little ferrous sulphate solution, and pour down the si
of the tubes a little pure strong sulphuric acid so that
forms a layer at the bottom of the tube. Note that
brown ring is formed where the layer of ac
touches the solution, and that the bro
ring has the same appearance in each tu

Nitrate not Retained.

This brown ring is formed by the reaction of the acid
the ferrous sulphate and the nitrate, and its intensity
a measure of the amount of nitrate present. Since
intensity is the same in each tube, the soil has eviden
not absorbed nitrate from the solution. This agrees w
our conclusion that nitrate is readily washed out of the s

Repeat the first part of this experiment with the superphosphate solution. To compare the amount of phosphate in the solution before and after it has been in contact with the soil, take 10 c.c. of each, add a few drops of ammonia, a little nitric acid and about 5 c.c. of ammonium molybdate solution, and warm gently. The original solution will give a conspicuous canary yellow precipitate. The solution, after contact with the soil, will only give a slight yellow colour, showing that almost the whole of the phosphate has been absorbed from the solution by the soil. This agrees with our conclusion that phosphoric acid is not washed out of the soil.

Phosphoric Acid is retained.

Potash is retained.

Now repeat the first part of the experiment with the muriate of potash solution. To 10 c.c. of the original solution add a drop of acetic acid and 5 c.c. of sodium cobaltinitrite. A considerable yellow precipitate will be obtained. Repeat the test with 10 c.c. of the solution which has been shaken with the soil. No yellow precipitate will be obtained, showing that the soil has absorbed practically all the potash from the solution. This agrees with our conclusion that potash is not washed out of the soil.

Ammonia is retained.

To find if soil absorbs ammonia we must proceed in rather a different way. Measure 1 c.c. of the sulphate of ammonia solution into each of two clean flasks and add to each 100 c.c. of distilled water. To one flask add 50 grams of soil, shake well, allow to stand and filter. Now pour 50 c.c. from the second flask into a glass cylinder, and 50 c.c. of the filtrate from the soil into a second cylinder. To each cylinder add 2 c.c. of Nessler's solution and stir. The solution which has not been in contact with the soil will develop a distinct brown colour owing to the ammonia which it [illegible] Only the faintest yellow tint will be formed in the solution which was shaken with soil, showing that t [illegible] absorbed nearly all the ammonia. Ammon [illegible], like phosphoric acid and potash is not wash [illegible] the soil. This is true as long as it remains in t [illegible] ammonia. But we know that ammonia in the s [illegible] changed to nitrate, and when this has taken pla [illegible] washed out if the crop does not absorb it.

[illegible] test the original solutions of sulphate of ammon [illegible] of potash by adding to each a few drops [illegible] They will all be found to be neutral. Repe the test with the same solutions which ha been shaken with soil. They will still neutral, although the soil has absorbed t ammonia and potash. Has the soil al absorbed the sulphate and chloride (muria [illegible] commercial name for chloride)? To the origir sulphate of ammonia solution add HCl and bariu chloride. A white precipitate of sulphate is forme Repeat the test with an equal volume of the same soluti after it has been shaken with soil, and compare the pr [illegible] They will be similar in the two cases showin [illegible] the soil has not absorbed the sulphate. Similar tes [illegible] HNO_3 and silver nitrate will show that the soil do [illegible] absorb the chloride.

Potash, Soda, and Ammonia retained at expense of Lime

How then does the solution remain neutral if the bases [illegible] and potash — are absorbed and the acids, sulpha [illegible] chloride are not? The only possible explanation that the bases have been replaced by an equivalent amou [illegible] other base. The most abundant base in the s [illegible] If the ammonia and potash have been replac [illegible] we ought to find lime in the solutions which ha been shaken with soil. Test these solutions with ace [illegible] and ammonium oxalate. A white precipitate will formed in each case, showing that lime is present. We may therefore conclude that potash and ammonia are absorbed in the soil being replaced by an equivalent amount of lime.

Part played by Clay in retaining Potash.

In Chapter V. when discussing the composition of clay, we found that clay as it occurs in the soil is a hydrated double silicate containing soda, potash, lime, and magnesia. When muriate of potash comes into contact with this complicated silicate the potash goes into the silicate and turns out an equivalent quantity of lime. The silicate being insoluble the potash is retained in the soil. The lime takes the place of the potash forming calcium chloride which is washed out of the soil. This is confirmed by the fact that the drainage water from the Rothamsted experimental field contains on the average 162 parts per million of lime and much more than this in the drainage from the plots manured with sulphates and chlorides.

Now test for lime in the nitrate of soda solution which was shaken with soil. We shall find that it too contains lime, and we must conclude that the soda has been absorbed in the soil, an equivalent amount of lime being washed out. This would not take place to a very great extent in farming practice, because the crops would absorb the nitrate and prevent it from being washed out in the drainage, and if the nitrate is not washed out it cannot carry lime with it.

Sulphates and Chlorides cause Loss of Lime.

These experiments enable us to form two important conclusions. The use of sulphates and chlorides and, to a less degree, nitrates, as manures causes the washing out of lime from the soil, and this may take place to a harmful extent. The Rothamsted drainage water contains 162 parts per million of lime. The rainfall at Rothamsted is 28 inches per annum, which is equivale to about 2,800 tons, or over 6,000,000 lb. per acre. If assume that one-third of the rainfall flows away in t drains, the loss of lime from the soil will be 162 × 2 1 or about 3 cwt. per acre per annum. Some lime would washed out of the soil under any conditions, becau calcium carbonate is soluble in water containing carbo acid, but the amount is comparatively small. The loss lime is much increased by the use of such manures sulphates and chlorides. When such manures are fr quently used it is wise to keep the percentage of lime the soil under observation. This will be discussed furth in the next chapter.

Lime can make Potash available.

How Potash Supply is maintained.

The second important point is that the turning out lime from double silicates by potash or so is a reversible action. If we add to the s large quantities of lime salts or of soda sal these salts will turn some potash out of t double silicates and make it available to crops. Und normal conditions we may imagine that the double si cates containing potash, soda, lime, and magnesia are equilibrium with the soil-water, which co tains in solution traces of potash, soda, a magnesia and considerable quantities of lin Crops gradually absorb from the soil-wat the potash which they require, and, as this occurs, lir goes into the double silicates and turns out more potas If now we manure the soil with a potash salt, at first tl dissolves in the soil water, but in doing so disturbs t equilibrium. Equilibrium is rapidly regained by t excess of potash going into the double silicate and turni out an equivalent quantity of lime.

By manuring the soil with lime salts, the equilibrium disturbed in the opposite direction, and is restored some of the excess of lime going into the double silicate and turning out an equivalent amount of potash. Thus the double silicates form a sort of "bank," which absorbs potash when it is added to the soil as manure, and tends to maintain a constant concentration of potash in the soil water. This concentration is, however, so low that the loss of potash when the soil-water escapes in the drains is almost negligible.

How Phosphoric Acid Supply is maintained.

Phosphoric acid in the soil behaves in much the same way, but the "bank" which retains it and keeps the concentration constant is not the double silicates, but various phosphates of calcium, and possible iron phosphate too. These phosphates, $CaHPO_4$, $Ca_3(PO_4)_2$, and $FePO_4$, are insoluble in water, but in the soil they probably exist in a condition of equilibrium with the soil water, which contains CO_2, $Ca(HCO_3)_2$, and a constant concentration of $CaH_4(PO_4)_2$, formed by the action of the CO_2 on the phosphates. If superphosphate is added, at first the equilibrium is disturbed by the presence of excess of $CaH_4(PO_4)_2$, but it is soon restored by the reaction of $CaH_4(PO_4)_2$ and $Ca_3(PO_4)_2$, thus—

$$CaH_4(PO_4)_2 + Ca_3(PO_4)_2 = 4CaHPO_4.$$

It is probably in this way that phosphoric acid is retained in the soil.

CHAPTER IX.

TESTING THE SOIL. LIME.

Lime is required in the soil for two purposes. Plant need a certain amount of lime which they get from th soil, so that lime is needed to supply the direct needs c crops for food. Crops also require certain conditions i the soil which can only be maintained in the presence c calcium carbonate.

Calcium Compounds in the Soil.

Lime exists in the soil in two forms, as calcium carbonate, and as silicates and other salt Both these forms can supply lime for plan food. Only calcium carbonate can maintai the soil in a suitable condition for the growt of crops.

The actual requirements of crops for lime are small—cereals for instance only require about 10 lb. of lime pe acre—and it is extremely rare to find a soil which canno supply the direct needs of crops for lime.

Calcium Carbonate often deficient.

Many soils, however, do not contain sufficient calciu carbonate to maintain a healthy conditio for crop growth. For our purpose therefor we can confine our attention to the lime i the soil which is in the form of calciu carbonate. We will take it that soils contain enough lim to feed our crops, and confine our enquiries to two points, namely, how calcium carbonate maintains the soil in a healthy condition, and how we can find out if a soil needs calcium carbonate.

Functions of Calcium Carbonate.

Plants can be divided into three classes with respect to their attitude towards calcium carbonate, namely those which will grow only if the soil contains abundance of calcium carbonate, those which do not mind whether calcium carbonate is abundant or not, and those which will not grow in the presence of appreciable quantities of calcium carbonate. Amongst our farm and garden crops leguminous plants such as sainfoin, lucerne, clovers, beans, and peas, and cruciferous plants such as turnips, swedes, and cabbages, belong to the first class, which will not grow in the absence of plenty of calcium carbonate. Cereals, mangolds, and potatoes, belong to the second class. They are not greatly influenced, except perhaps indirectly, by the amount of calcium carbonate in the soil. None of the ordinary farm crops belong to the third class which will only grow if calcium carbonate is deficient. This class, however, includes certain garden plants such for instance as rhododendrons, azaleas, ericas, and many common weeds such as sorrel, spurrey, corn chrysanthemum, and stinking Mayweed. The presence of these weeds is a sure indication that the soil is deficient in calcium carbonate.

Calcium Carbonate checks certain Weeds.

Most of the common crops grown in rotation husbandry, therefore, like abundance of calcium carbonate in the soil, and the rest do not object to it. Since we cannot vary the amount of calcium carbonate from year to year, we must maintain plenty in the soil for those crops which require it.

Calcium Carbonate prevents Acidity.

The reason why most of our crops require plenty calcium carbonate in the soil is that those crops cann grow in an acid soil, and calcium carbonate is the comm constituent in the soil which prevents t soil becoming acid. Acids are formed the soil by the decomposition of the orga matter. If calcium carbonate is present, reacts with the acids as soon as they are formed, pr ducing carbon dioxide and neutral calcium salts of t acids.

Calcium Carbonate is necessary for Nitrification.

Another reason why calcium carbonate is beneficial crop growth is that it is necessary for t growth of the nitrifying microbes. In i absence these microbes cannot grow, nit fication ceases, and the crops cannot g nitrate which is the form in which th prefer to absorb their nitrogen.

Calcium Carbonate prevents Finger and Toe.

Although these useful microbes cannot grow in t absence of calcium carbonate, certain m croscopic fungi, for example plasmodiophor brassicæ, the fungus which causes finge and toe disease in turnips swedes an cabbages, cannot grow if calcium carbon ate is fairly abundant. The best, indeed the only wa of preventing this disease is to maintain a good suppl of calcium carbonate in the soil. Calciu carbonate is specially important in cla soils because when dissolved in the soi water as calcium bicarbonate, it flocculate the clay particles and keeps the soil in good workab condition.

Calcium Carbonate flocculates Clays.

Evidently if we wish to keep our soil in a good state o productivity it is most important that the supply of ca cium carbonate should be adequately maintained.

Amount of Calcium Carbonate in Soils.

The percentage of calcium carbonate in soil varies very greatly. Some soils on the chalk may contain 10 or even 20 per cent. Other soils, as the green sand or the red sandstone, may contain none at all. The fact that a soil overlies the chalk is no guarantee that it will contain plenty of calcium carbonate. Indeed, it is quite common to find soils in the Eastern Counties overlying chalk which are so deficient in calcium carbonate that they are infested with spurrey, corn chrysanthemum, and finger and toe. The only way to make sure that sufficient calcium carbonate is present in a soil is to observe the weeds which grow on it and to test it chemically.

Testing for Sourness.

Fortunately calcium carbonate is quite an easy compound to recognise. If a soil contains none at all it will almost certainly be acid. Lay a square of blue litmus-paper on a clock glass, and pour on to it a small heap of the soil to be tested. Moisten the soil with distilled water, cover it with a beaker to keep away acid fumes, and leave it for a few minutes. Wash away the soil with distilled water. If the soil was acid the paper will have been reddened where it was in contact with the soil. If a soil is found to be acid in this way it is certainly very deficient in calcium carbonate and it must be limed, chalked, or marled before it can be really productive.

Testing for Calcium Carbonate.

A more direct way of testing a soil for calcium carbonate is to take advantage of the fact that it is the only constituent present in the soil in appreciable amount which gives off gas when treated with hydrochloric acid. Put a few grams of the soil to be tested in a small beaker. Add enough water to moisten it and stir with a glass rod until all the air is worked out of the wet soil. Now add a little strong hydrochloric acid to decompose any calcium bonate which may be present.

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$

If distinct effervescence can be seen, the soil cont sufficient calcium carbonate. If there is no visible ef vescence, but the crackling of gas bubbles can be he when the beaker is held to the ear, the amount of calci carbonate present is approaching deficiency. If no eff vescence can be perceived either by sight or hearing, soil is deficient in calcium carbonate.

Determining Lime Requirement.

It is possible to make this method more precise mixing the soil and the acid in an app ratus which makes it possible to measu weigh or titrate the quantity of C evolved.

The best precise method, however, is to estimate what called the lime requirement of the soil, that is to say, t amount of calcium carbonate the soil can absorb. W have seen above that when calcium carbonate comes in contact with soil it combines with and neutralises an acids which may be present in the soil. We saw in th last chapter that calcium carbonate could react with th double silicates of the soil. Now in both these cases, th calcium carbonate is converted into something differen To measure the lime requirement, we find out how mu calcium carbonate the acids and double silicates in th soil can use in this way, and this is supposed to be measure of the amount of lime required to neutralise th soil.

Method.

The method is carried out as follows:—A quantity lime-water is prepared by shaking som quick lime with distilled water and filterin A current of carbon dioxide gas is passed through th lime-water until the $CaCO_3$, which is first precipitated, completely redissolved by being transformed into bicarbonate. Thus—

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2.$$

200 c.c. of this solution of calcium bicarbonate is now measured out into a bottle, and 5 grams of the soil to be tested added to it. The bottle is shaken at intervals for four hours.

Meantime 100 c.c. of the bicarbonate solution is measured into a beaker. A few drops of methyl orange is added, and standard hydrochloric acid, of the strength known as N/10, is carefully run into the yellow solution, which is shaken all the time, until the addition of a single drop of acid turns the colour from yellow to pink. At this point we know that the acid has neutralised all the calcium bicarbonate. Let us suppose that 37·3 c.c. of N/10 acid was required.

After four hours the contents of the bottle are poured on to a filter. 100 c.c. of the filtrate is measured into a beaker, a few drops of methyl orange is added, and N/10 hydrochloric run in as before until the colour just changes from yellow to pink.

If the soil contains plenty of calcium carbonate, 37·3 c.c. or more of the acid will be required. If the soil was deficient in calcium carbonate it will have absorbed some of the calcium bicarbonate from the solution. The solution will, therefore, not be able to neutralise so much acid. Let us suppose that it neutralises only 34·6 c.c. Before shaking with the soil, 100 c.c. of the solution neutralised 37·3 c.c. The soil has, therefore, taken from the solution an amount of calcium carbonate equivalent to 37·3 — 34·6 c.c. or 2·7 c.c. N/10 acid. Now 1 c.c. N/10 HCl neutralises ·005 gram $CaCO_3$. 2·7 c.c. must, therefore, have neutralised 2·7 × ·005 gram $CaCO_3$ = ·0135 gram $CaCO_3$. Since 5 grams of soil was shaken with 200 c.c. of solution, and only half this solution was titrated by the acid, ·0135 gra is the amount of $CaCO_3$ absorbed by 2·5 grams of so The soil, therefore, absorbs $\frac{\cdot 0135 \times 100}{2\cdot 5}$, or ·54 per cent. its own weight of $CaCO_3$.

If the soil weighs 2½ million lb. per acre, the lime r quirement will be $\frac{\cdot 54 \times 2500000}{100}$, or 13,500 lb., or near 6 tons of calcium carbonate per acre. This is supposed t be the amount of calcium carbonate required to make tl soil neutral. It is seldom that so high a lime requiremei is found. Such a soil would be greatly improved b addition of 2 or 3 tons of lime, or 6 to 7 tons of chalk o ground lime-stone.

Importance of Testing Soil.

In the last three chapters we have seen that a grea many useful facts can be learned by exper menting with a soil in the laboratory. C these, the exact knowledge as to whether th soil is deficient in calcium carbonate is of the most imme diate use. Fortunately, too, it is the easiest fact to fin out. Every farmer and gardener should make sure tha his soil contains a sufficiency of calcium carbonate. If h has any doubt on the subject he should take a sample o his soil, as directed in Chapter II., and either test it him self by one of the methods described above, or send it t the county analyst or to the local college.

If he finds that it is deficient in calcium carbonate, h can greatly improve its productivity by liming, chalking or marling. How these operations are carried out will b described in a later chapter. Such treatment will no only make the soil more suitable for ordinary crops, bu in addition will improve nitrification, make the soil easie to cultivate if it is a clay soil, and eradicate certain ver troublesome weeds and fungoid diseases. It will als make it quite safe to use acid manures, such as superphosphate, which should not be used on soils deficient in calcium carbonate. Thousands of acres are kept below their proper level of productivity for want of the simple precaution of testing for calcium carbonate. If this factor is deficient, no amount of drainage, cultivation, or manuring will maintain a satisfactory level of productivity.